NATO
OTAN

Science and Technology Organization

2017 HIGHLIGHTS

Empowering the Alliance's Technological Edge

Foreword

FOREWORD

THE NATO SCIENCE AND TECHNOLOGY ORGANIZATION "EMPOWERING THE ALLIANCE'S TECHNOLOGICAL EDGE"

Instabilities in regions close to NATO territory did not disappear in 2017 and are likely to remain significant for many years to come. All evidence indicates that the Alliance will face increasing pressure as it executes its role in helping to maintain the world's strategic balance. Global trends such as demographic and economic shifts, increasingly rapid technological advances and proliferation, pressure on scarce resources, and the changing nature of conflict portend a complex geopolitical and operational environment for future NATO actions.

To safeguard our freedom and shared values, it is of critical importance for the Alliance and its partner nations to maintain the edge in defence and security. Discovering, developing, and utilising advanced knowledge and cutting-edge Science and Technology (S&T) is fundamental to maintaining the technological edge that has enabled our Alliance forces to succeed across the full spectrum of operations over the past decades. The NATO Science and Technology Organization (STO), along with its predecessor organizations, have been instrumental in enabling that success, both within the nations and for NATO itself.

In 2017, the STO continued to deliver a healthy and robust Programme of Work (PoW) to the Alliance and its partner nations by creating a shared understanding of state-of-the-art technologies, supporting capability development, fostering partnerships, and providing knowledge and advice to senior decision-makers. One example includes the publication of a Technology Trends report, which highlights a spectrum of technologies that could affect our military capabilities and challenges over the coming decades. Similarly, the delivery of technology roadmaps for Anti-Submarine Warfare (ASW) and Naval Mine Warfare (NMW) under the Maritime Security Initiative provides a framework for linking national investments in relevant technologies to future critical capabilities.

Allied nations have expressed their intent to spend more, and to do so wisely. The STO Collaborative Programme of Work (CPoW) grew to more than 250 activities, while the network of scientists, engineers, and analysts active in the STO increased to roughly 5,000. The STO network draws upon the expertise of more than 200,000 colleagues in allied and partner nations. The activities are supported and enabled by the STO Collaboration Support Office (CSO), which provides knowledge management tools, personnel, and fiscal resources to manage planning processes, facilitate execution and document products/results.

The STO Centre for Maritime Research and Experimentation (CMRE) advanced capability development and interoperability in areas such as autonomous maritime unmanned systems and underwater communications. This provided an enhanced understanding of advanced technologies and systems by innovative research and experimentation at sea in 2017. For example, sailing under the Italian Navy flag and operated by an Italian Navy crew, the NATO Research Vessel (NRV) *Alliance* was used by CMRE to support key technological objectives in major operational exercises focused on ASW in the North Atlantic.

The STB improved its STO governance as well as NATO S&T unified governance efforts. Together, this builds greater coherence across the S&T community. Examples include: initiating the development of a new, more actionable NATO S&T Strategy; responding to significant changes in the strategic and technological landscape; updating and approving the 2017 NATO S&T Priorities in alignment with the Alliance's updated military requirements; and launching two important CPoW themes to focus efforts on rapidly emerging and important operational challenges.

By providing a critical venue for knowledge development and delivery, the STO remains committed to its foundational principle: bringing together subject matter experts from across the scientific spectrum with military end-users in order to inform decision-makers on emerging challenges and opportunities, and to ensure the technological advantage of the Alliance and its partners.

I look forward to continue serving the Allies, NATO, and STO, and consider it a privilege to work together with the fine professionals from across the Alliance and its partner nations.

NATO Chief Scientist (CS)
Science and Technology Board (STB) Chairman

TABLE OF CONTENTS

NATO Science and Technology Board Perspective

SCIENCE AND TECHNOLOGY – A FORCE MULTIPLIER FOR THE ALLIANCE, ITS MEMBERS AND PARTNERS

As a political-military Alliance, NATO's structures and processes are designed to support, inform and facilitate strategic-level planning and decision-making. In pursuing its core tasks, the Alliance benefits significantly from a range of products delivered and services rendered by Science and Technology (S&T). These include:

- maintaining the technological and knowledge advantage;
- providing the evidence-base to underpin informed decision-making;
- mitigating evolving threats and risks, including supporting public diplomacy.

NATO's topical interest in S&T broadly covers basic and applied research across the physical, information, medical, and social sciences. To facilitate the generation and exchange of knowledge and technology, and to promote the exploitation of S&T results, NATO provides trusted platforms and frameworks open to scientists, engineers, operators, and policy-makers. Through these networks, participants capitalise on the diversity of approaches and perspectives to leverage and augment their own resources and investments. The nature of NATO S&T activities ranges from *ad hoc* knowledge exchange to jointly planned and executed projects and programmes. The majority of these S&T efforts are funded directly by allied and partner nations.

NATO S&T thrives on the voluntary collaboration between a broad range of stakeholders from many different military, organizational and scientific backgrounds, each participating according to their organizational capabilities, interests and needs. In addition to allied and partner nations, many NATO committees, commands, and staffs have stake in NATO S&T as they:

- benefit from S&T as customers, exploiting S&T results without being actively involved in S&T generation;
- execute dedicated S&T programmes of various scales, topical portfolios, or funding mechanisms;
- influence requirement setting or investment decisions to inform and orient future S&T activities.

These breadth and diversity of stakeholders' interests and portfolios make indispensable the close co-ordination, co-operation and collaboration between all stakeholders for their individual mission success and for the overall success of the Alliance.

Avoiding unnecessary duplication, identifying complementarities, and exploiting synergies have become **the hallmarks of NATO S&T**. Taken together, they promote the alignment of S&T activities with S&T requirements, so that scarce resources are efficiently allocated to effectively meet the needs of the Alliance, its members and its partner nations.

THE NATO SCIENCE AND TECHNOLOGY ORGANIZATION

The NATO Science & Technology Organization (STO) welcomes participants and contributors from allied and partner nations who come from government, industry, or academia. Within this trusted network of experts, the STO plans, executes and delivers a Programme of Work (PoW) that covers the full spectrum of defence- and security-related S&T. This programme contributes to capability development, supports threat mitigation, and provides advice to decision-makers, thereby supporting the core tasks of the Alliance. In pursuing its mission, the STO positions S&T to the strategic advantage of nations and NATO.

THE NATO SCIENCE AND TECHNOLOGY BOARD

The STO is governed by the NATO Science and Technology Board (STB), which comprises the senior national defence S&T leaders and representatives of all relevant NATO S&T stakeholders. The STB reports to the North Atlantic Council and is in charge of NATO-wide S&T governance, without prejudice to the responsibilities and authority of individual stakeholders.

The STB plays a critical role in developing and maintaining strategic direction and guidance for S&T across NATO, serving as the focal point for co-ordinating all S&T programmes and activities within NATO. Internal to the STO, the STB guides and directs the future PoW and oversees its delivery.

DELIVERING THE PROGRAMME OF WORK...

The STO delivers the largest S&T PoW within NATO S&T, designed to enhance multinational collaboration by making available the knowledge, skills, and investments of all contributors. It is predominantly funded by participating nations in line with their objectives; to a lesser extent, it is funded by NATO in support of the over-arching objectives of the Alliance.

...THROUGH A COLLABORATIVE NETWORK...

With more than 5,000 active Subject Matter Experts, the STO attracts the world's largest network of defence and security researchers, scientists and engineers, addressing all military-relevant aspects of S&T through seven domains:

- Applied Vehicle Technology (AVT);
- Human Factors and Medicine (HFM);
- Information Systems Technology (IST);
- NATO Modelling and Simulation Group (NMSG);
- Systems Analysis and Studies (SAS);
- Systems Concepts and Integration (SCI);
- Sensors and Electronics Technology (SET).

THE NATO CHIEF SCIENTIST

Leadership of the STO is exercised by the NATO Chief Scientist, who chairs the STB and serves as the scientific advisor to senior NATO leadership.

He is supported by the Office of the Chief Scientist at NATO headquarters in Brussels, Belgium.

In each domain, several hundred national subject matter experts are actively engaged in the execution of commonly agreed S&T activities such as joint research projects, conferences, workshops, lectures, or technology demonstrations. Every year, the STO runs well over 200 such activities.

NATO provides executive support to this network and its PoW through the Collaboration Support Office (CSO), located in Neuilly-sur-Seine, France.

...AND A DEDICATED RESEARCH LABORATORY

The Centre for Maritime Research and Experimentation (CMRE) is a customer-funded laboratory focused on the underwater domain. Nations reduce the cost and risk of innovative work by collaborating through the Centre and employing its unique facilities.

Using its own capabilities, infrastructure and personnel, the Centre carries out projects and experiments to deliver military relevant, validated S&T results that advance basic understanding of the maritime environment as well as naval capabilities.

Key enablers for delivering the CMRE's programme are its research vessels: the NATO Research Vessel (NRV) *Alliance* and Coastal Research Vessel (CRV) *Leonardo*. With year-round global access to the ocean and state-of-the-art scientific facilities, satellite communications and reconfigurable deck equipment, experimentation can range from concept development through to prototype demonstration in NATO and multinational maritime exercises.

The Centre operates out of La Spezia, Italy.

STO Executive Body Perspectives

THE OFFICE OF THE CHIEF SCIENTIST (OCS)

The OCS is the anchor of the STO at NATO Headquarters (HQ). With its small staff, the OCS supports the Chief Scientist in his two essential functions: as the Chair of the STB, and as the senior scientific advisor to NATO leadership.

Figure 1: Dr. Thomas Killion, NATO Chief Scientist, STB Chairman.

Beyond providing executive support to the STB and its decision-making, the OCS acts as a bridge between the STO programme of work (PoW) and its end-users represented at NATO HQ. To that end, the OCS works with the S&T results generated through the PoW, and promotes their use in the political and military context. Engaging the committees and staffs at NATO HQ, the OCS selectively highlights the most relevant and recent S&T results that are available to inform NATO and national decision-making.

Under its Maritime Security Initiative, the OCS developed roadmaps on national S&T investments, contributing to the development of future anti-submarine warfare and naval mine warfare capabilities. These technology roadmaps are naturally linked to the capability roadmaps that are used by the NATO Defence Investment Division to track the delivery of critical capabilities for the Alliance.

During the Alliance Future Surveillance and Control (AFSC) system pre-concept stage, the OCS led the AFSC Solutions Working Group, drawing on the STO's wide network of Subject-Matter Experts (SMEs). In 2017, the OCS worked with NATO Support and Procurement Agency (NSPA) to develop an approach for conducting key small-scale studies, using national experts to address critical issues in information assurance and in spectrum requirements and management. During the concept stage, the STO will remain engaged to provide independent S&T advice.

This year also saw the publication of a new STO Technology Trends report. This document builds upon the Technology Watch (TW) efforts of the Collaborative Programme of Work (CPoW) Panels and Group, and identifies a spectrum of emerging technologies that will have significant impacts on military capabilities and challenges in the coming decades.

As Chief Scientist, Dr. Thomas Killion has focused the OCS to enhance the impact of S&T for the Nations and NATO. One of his first initiatives was to pursue the development of a new, more actionable NATO S&T Strategy, responding to significant changes in the strategic and technological landscape.

THE COLLABORATION SUPPORT OFFICE (CSO)

The Collaborative Programme of Work (CPoW) remains the cornerstone of NATO Science and Technology. The network delivering the CPoW is comprised of about 5,000 scientists, engineers, and operations analysts from NATO and partner nations. The CPoW is divided into 6 technical panels and 1 technical group, which are led by Panel Chairs and Vice-Chairs from the nations and the Panel Executives who work from the Collaboration Support Office (CSO).

Mr. Alan Shaffer, Director of the CSO, believes that the CPoW is more important today, than it has been at any time since the Cold War. Simply, the security challenges facing the NATO nations and the increased complexity of the technological milieu are putting pressure on NATO.

While Defence spending in the nations increased over 3% last year, only 5 NATO nations are meeting the defence pledge of investing 2% of their Gross Domestic Product (GDP) in defence. As spending increases, some should come to advanced technology. The CPoW is vital to aligning this spending to the greatest need. This is important given that the rest of the world is closing the advanced technology gap has benefitted in the past quarter century. With the declaration of initial operational capability in March 2017 of the Chengdu J-20 (China), NATO no longer has the only operational fifth generation aircraft. The Russian Sukhoi SU-57 is nearing operational fielding. Other advanced systems like Chinese and Russian surface to air missiles and now operational ultra-quiet submarines are eroding NATO's advantage. The path to retaining or regaining this advantage is through the application of new technology and to accelerate the demonstration and fielding of this new technology.

The CPoW network is working hard at gaining knowledge and experience with these new technologies, but the path is not through old models of serial development then fielding. Rather, it is through an increased government-industrial partnership and application, where possible, of commercial technology tuned for military application. The Science and Technology Organization (STO) network of scientists allows defence researchers to easily interact with both Industry and Academia, and to expand demonstrations of technology. Over the past two years, the CPoW has increased emphasis on military relevance, and expanded the number of Collaborative Demonstrations of Technology (CDT) four-fold. The network has developed experiments to be injected into NATO exercises such as TRIDENT JUNCTURE 2018, where 5 STO experiments will be conducted.

The vision for the CSO is to retain its status as the collaboration engine of choice for the NATO and partner nations. In addition, it seeks to continue striving for military relevance in all projects and activities, while enhancing the technical quality of work done in the CPoW. But the CPoW needs to more aggressively "sell" their product–work that is the product of the Scientific and Technical Committees comprised of contributions from the nations.

Figure 2: CSO staff.

The Director also believes that the CPoW needs to aggressively seek out collaboration in new areas of technical development, such as: hypersonic flight, biological science and artificial intelligence, quantum physics, and advanced electronic warfare and cyber components and capabilities. The network is responding to this call, as well as expanding the focus on the first 3 "themes":

- autonomy;
- military decision making using artificial intelligence and big data;
- operations in a contested urban environment.

In these areas and many more, the CPoW is responding to the future military need of the NATO nations. This is an exciting time to work in NATO S&T and for the development of national capabilities.

> "The path to retaining or regaining the technological advantage is through the application of new technology and to accelerate the demonstration and fielding of this new technology."

THE CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION (CMRE)

In one form or another, CMRE has served NATO for almost 60 years as a hub for multinational collaboration. It provides a place where scientists and engineers from across the Alliance gather to advance the understanding of the maritime environment and its impact on operational applications. At the recent Chiefs of Transformation Conference, CMRE was singled out by Supreme Allied Commander Transformation (SACT) GAA Denis Mercier. "Based on the contributions of the NATO Centre for Maritime Research and Experimentation, the Norwegian development of autonomous underwater vehicles in the context of covert underwater operations demonstrates how future promising technologies could deliver the required effects differently. The ability to deploy autonomous underwater vehicles at greater distances using these emerging technologies could introduce new potential applications for surveillance and reconnaissance, mine countermeasure, anti-submarine warfare and anti-surface warfare, with significant operational benefits and reduced risk to personnel."

EUROPEAN COMMISSION (EC) & EUROPEAN DEFENCE AGENCY (EDA)

In 2017, consortia involving CMRE have been awarded funding for 3 more EC projects. Recently, a technological demonstrator for enhanced situational awareness in a naval environment, involving CMRE, has been accepted as the first project in EDA's preparatory action on defence research.

THE SHIPS

The time spent at sea by both NATO Research Vessel (NRV) *Alliance* and Coastal Research Vessel (CRV) *Leonardo* increased as both vessels became increasingly involved in operational experimentation and participation in NATO exercises. ALLIANCE returned to operations in the High North combining research, NATO exercises and Italian Navy hydrographic tasking. This once again proved the utility of the ship and the importance of operating in this strategic region. LEONARDO undertook a significant task for the US Department of Defense DoD Defense POW/MIA Accounting Agency (DPAA).

SCIENTIFIC TRIALS

Long Range Glider Missions for Environmental Characterisation (LOGMEC) ran for two months. Oceanographic and acoustic measurements taken by 5 underwater gliders in the Mediterranean were transferred to NATO and national command and control systems *via* the Coalition Warfare Interoperability Exercise (CWIX) based at the Joint Force Training Centre in Poland. This was conducted in conjunction with a sea trial from which information was fed into NATO and national C2 and decision support systems. Separately, the Centre advanced future mine-hunting capabilities in the context of a Hellenic Navy exercise in the Adriatic. That and other scientific achievements are documented later in this brochure.

Figure 3: Alliance during NATO exercise.

OPERATIONAL EXPERIMENTATION

NRV Alliance was fully integrated into exercise Dynamic Mongoose with the maritime unmanned systems and the decision support projects of the ASW program. The Centre also provided meteorological and oceanographic services to the task groups, and fed the ASW decision support service on board the Standing NATO Maritime Group 1 (SNMG1) flag ship, the His Norwegian Majesty Ship (HNoMS) *Roald Amundsen*. Interoperable underwater digital communications were introduced successfully in the submarine rescue exercise, Dynamic Monarch, paving the way for the seamless employment of unmanned vehicles.

"Compass award, Scientific Achievement Award, 2017 has been an important year for CMRE in managing both internal and external change, while developing additional business opportunities and strategic relationships beyond the traditional NATO maritime S&T programme."

NATO STO
Programme
of Work

ENABLING FUTURE MILITARY CAPABILITIES

Enabling future military capabilities is a complex process in which the nations and NATO work closely together over the long-, mid- and short-term. Many elements come into play to finally arrive at superior military capabilities at the right moment; human brainpower, scientific understanding and technological competency are critical requirements. Enabling future military capabilities by investing sufficiently and wisely in S&T is at the heart of NATO's strategy for keeping our people safe by deterrence.

The outline of STO PoW activities enables the development of future military capabilities:

- Autonomy from a System Perspective (SCI-296)
- Coherent Electronic Attack on Advanced Radar Systems (SCI-252)
- Cyber Defence Situational Awareness (IST-108)
- Development of a Depository of Fast and Reliable Detection Methods for Vector-Borne and Zoonotic Pathogens (HFM-230)
- Directed Infrared Countermeasure (DIRCM) State of the Art and Flight Testing Methodology (SCI-237)
- Future Rotorcraft Technologies (AVT-ST-005)
- Heterogeneous Tactical Networks - Improving Connectivity and Network Efficiency (IST-124)
- Integrated Virtual NATO Vehicle Development (AVT-265)
- Integration of CBRN Physical Protective Measures to Lessen the Burden on Personnel (HFM-199)
- Intelligence Exploitation of Social Media (SAS-IST-102)
- Modelling and Simulation as a Service (MSG-136)
- Reliable Prediction of Separated Flow Onset and Progression for Air and Sea Vehicles (AVT-183)
- Sensitive Equipment Decontamination (HFM 233)

AUTONOMY FROM A SYSTEM PERSPECTIVE (SCI-296)

Many prospective advantages of Autonomous Systems (AS) are becoming increasingly accepted as technologies mature. However, AS capabilities have typically been developed for component parts (*i.e.*, a technological perspective) without sufficient consideration of the respective roles of the Human and the Machine (HM) and their interdependence interdependence (*i.e.*, a system perspective). This Specialists' Meeting (SM) activity employs a system perspective investigation of AS.

Dr. Jason Stack, USA, Office of Naval Research (ONR) and Ms. Caroline Wilcox, CAN, Defence Research and Development Canada (DRDC)

BACKGROUND AND MILITARY RELEVANCE

Autonomy is a broad topic with far-reaching implications to NATO. A system perspective of autonomy considers all physical domains (*i.e.*, undersea, surface, ground and air); autonomous platforms, systems and subsystems (both centralised and distributed); and the relevant aspects of cyber. Weaponised and non-weaponised applications of autonomy should also be considered, since there is a large and diverse set of NATO applications that do not involve lethal force.

OBJECTIVES

The overarching objective of this SM identified areas where NATO should increase scientific and technical focus toward AS. Three underlying objectives were defined:

- understand what levels of HM interdependence are currently enabled by the state-of-the-art in autonomy;
- assess where increases in either autonomy or HM interoperability would cause an improvement in existing or novel applications;
- assess the resulting S&T advances, limitations, shortfalls and open issues from the first two objectives and plot a way forward.

S&T ACHIEVEMENTS

This SM established a community of interest for AS. In total, 17 topics for collaboration were identified in the areas of security and safety of AS, Verification and Validation (V&V), trust, HM teaming, interoperability and novel concepts. Going forward, these topics are being used to encourage a critical mass of collaborators using a multidisciplinary approach.

SYNERGIES AND COMPLEMENTARITIES

Affordability and development timelines emerged as topics that require a myriad of considerations that should not overly constrain AS. This challenges the S&T community and leads to future cost *versus* capability comparisons to quantify the effectiveness of a large number of low-cost AS *versus* a small number of high-cost AS.

Figure 4: Ground-based autonomous system.

EXPLOITATION AND IMPACT

Key findings were identified pertaining to establishing and calibrating trust in HM interdependence, particularly in view of the artificial intelligence that will be inherent in many AS and the requirement for shared situational awareness. Other findings include new paradigms for AS designs that adapt to evolving circumstances and the associated training and V&V of the HM team.

> "Decentralisation, uncertainty, complexity… Military power in the 21st century may be defined by our ability to adapt–adaptation is THE underlying foundation of autonomous technology."

CONCLUSION

The SM was the first time a cross-panel, multi-disciplinary approach was undertaken to address a Science & Technology Board (STB) request to employ a thematic approach in developing the Science & Technology Organization (STO) Collaborative Programme of Work.

COHERENT ELECTRONIC ATTACK ON ADVANCED RADAR SYSTEMS (SCI-252)

The Task Group (TG) was able to conduct field trials and simulations against the following set of radars technologies: Synthetic Aperture Radar (SAR), Inverse SAR (ISAR), High Range Resolution (HRR) and Passive Coherent Location (PCL). The results of the field trials and simulations give NATO scientists a fundamental understanding of the characteristics and techniques of Electronic Countermeasure (ECM) required to defeat those radars. The ever-evolving nature of this field, however, requires continuous refinement.

Mr. Dietmar Matthes, DEU, Fraunhofer-Gesellschaft

BACKGROUND AND MILITARY RELEVANCE

Today, there is an increasing number of advanced radar systems that are used to perform various tasks in the field of surveillance and target acquisition, as well as Intelligence, Surveillance and Reconnaissance (ISR). The current trend in the development of radar systems is towards more flexibility, lower cost and power consumption, and smaller size. Extensive digital signal processing has enabled for increased radar capabilities and more resistance to CMs. Conventional jamming techniques may not be effective against advanced radars, and it is essential to further develop and test Electronic Attack (EA) and Electronic Protection (EP) technologies and techniques against these radars.

OBJECTIVES

The main objective of the Research Task Group (RTG) was to expand upon the findings of SCI-190, *Electronic Countermeasures to Radar with High-Resolution and Extended Coherent Processing*, and further develop jamming techniques against SAR, ISAR, HRR and PCL radar systems. New efforts are being made in the requirement to counter the advancing application of radars with Low Probability of Intercept' (LPI) signal characteristics.

S&T ACHIEVEMENTS

The RTG investigated the credibility of jammer-generated false targets against radars with imaging capabilities. The results of target classification were compared between real targets, simulated target signatures and jammer-generated false targets based on both real and simulated signature data.

SYNERGIES AND COMPLEMENTARITIES

Competing with ever-evolving technologies for target acquisition, ISR and the application of the Electromagnetic (EM) spectrum by advanced radar systems, this study is mainly relevant to NATO's Long Term Capability Requirements (LTCRs) "Denial of EM spectrum," "ISR – Collection Capability," as well as "ISR – Processing, Fusion and Exploitation."

EXPLOITATION AND IMPACT

The denial of the EM spectrum by deceptive jamming will enable EP and the safe operation of platforms. The prevention of classification, forcing false classification or the generation of credible synthetic false targets are important tasks in the field of CMs.

> "Deny, degrade or disrupt the adversary's ability to use the electromagnetic spectrum to their advantage."

CONCLUSIONS

The TG presented several weaknesses of new radar threats when affected by advanced coherent EA techniques. Continued investigations performed by the TG is therefore highly recommended to keep NATO Allies in possession of advanced jamming and deceiving techniques against modern radar systems. Further recommendations are made for EPs to protect their own operating radar systems.

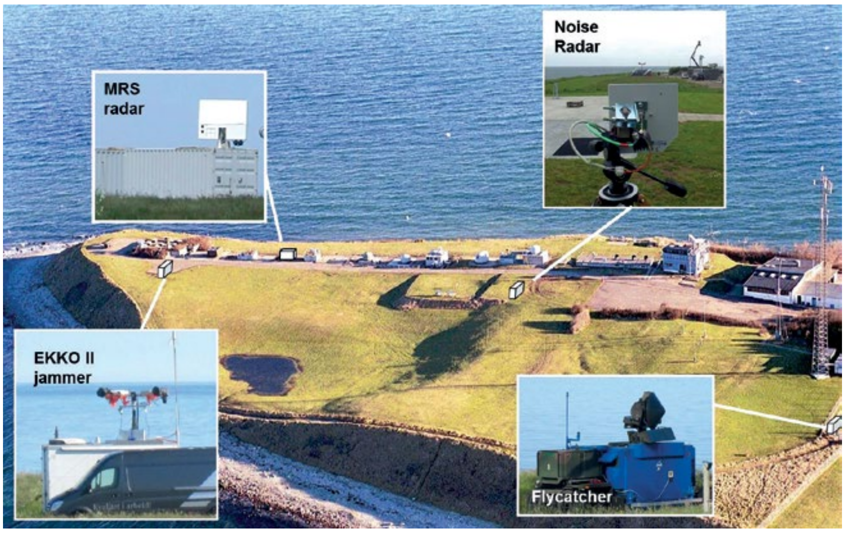

Figure 5: Signal jamming experimentation setup.

CYBER DEFENCE SITUATIONAL AWARENESS (IST-108)

IST-108 conducted investigation and analysis across the domain of Cyber Defence Situational Awareness (CDSA), and contributed to various situational awareness topics including situational awareness metrics, visualisation and mission assurance. Notable results of the work include development of methods and techniques to evaluate cyber operator levels of cyber situation awareness according to established situation awareness concepts.

Mr. Douglas Wiemer, CAN, RHEA Group, Director Security and Crisis Management

BACKGROUND

NATO needs to develop urgently and effective CDSA capability to respond to the danger of cyber attacks. This can be achieved by developing capabilities aimed at effective perception, comprehension and projection of the cyber situation. IST-108 provides a forum in which NATO and the nations can leverage each other's advances in the area of CDSA requirements, concepts and methods, leading to improved operational effectiveness.

OBJECTIVES

The objectives of the IST-108 Research Task Group (RTG) were to:

- advance research and technology in CDSA concepts as a step towards developing and refining related metrics, standards, visualisations and mission assurance practices; and
- influence development of CDSA techniques, technologies and procedures.

S&T ACHIEVEMENTS

The IST-108 RTG made significant advances in the following areas:

- developing a common definition for CDSA;
- documenting CDSA requirements in the areas of visualisation, metrics and mission assurance;
- promoting use of scientific methods for CDSA requirements analysis including Mission Function Task (MFT) analysis and Goal Question Metric (GQM) techniques;
- conducting experimental assessment of the Situation Awareness Global Assessment Technique (SAGAT) for evaluating cyber operator SA levels along the SA dimensions of perception, comprehension and projection.

SYNERGIES AND COMPLEMENTARITIES

The IST-108 RTG established effective synergies among multiple NATO Science and Technology Organization (STO) panels and activities including MSG-117, SAS-106, IST-110, IST-117, IST-148 and AFCEA.

> "Within the domain of CDSA, the sheer volume of information can be overwhelming to the cyber operator, and effective methods to increase operator levels of CDSA are essential."

EXPLOITATION AND IMPACT

The development of cyber situation information is dependent on the information available from cyber sensors and related sources. This information must also be placed within a context relevant to mission assurance. Application of CDSA methods explored by IST-108 have high potential for improved cyber operational effectiveness.

CONCLUSIONS

The CDSA methods explored establish the foundation for potential improvements in cyber operator SA levels and response effectiveness. Notable achievements were made in areas of MFT and GQM, application of the SAGAT to CDSA, and the collected view of CDSA requirements.

Figure 5 demonstrates the results of the experimental use of SAGAT applied to CDSA operator evaluation. Following the SAGAT methods, 20 teams (A – T) participating in Locked Shields 2016 where asked a series of questions related to their current cyber situation. The results displayed in the chart as blue bars represent their perception/comprehension of the percentage of compromised hosts. The red line indicates the actual percentage of compromised hosts at the time of the SAGAT evaluation during the exercise. The intersection of blue bars and red lines (*e.g.*, teams A, B, C, J and P) indicate teams having strong correspondence between their perception/comprehension understanding of the cyber situation and the actual cyber situation, meaning they have a high level of CDSA. Meanwhile, cases where the red line is far from the blue bars indicates that these teams have very poor CDSA levels compared to the actual situation.

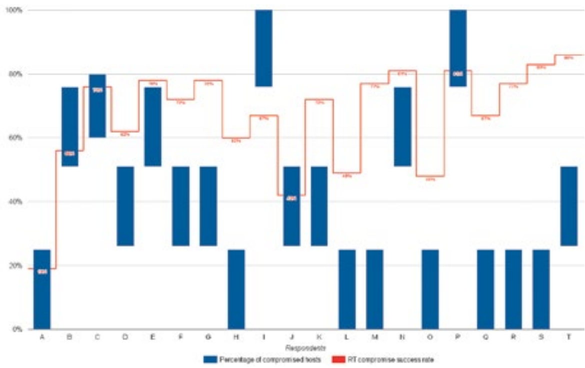

Figure 6: Example results of Blue Team (BT) Cyber Operator situation awareness evaluation using SAGAT compared to actual Red Team compromise. (Courtesy Mauno Pihelgas, Locked Shields 2016 staff.)

DEVELOPMENT OF A DEPOSITORY OF FAST AND RELIABLE DETECTION METHODS FOR VECTOR-BORNE AND ZOONOTIC PATHOGENS (HFM-230)

HFM-230 identified priority zoonotic and vector-borne pathogens, and compiled a consolidated list of fast and reliable detection methods for each of these pathogens.

Ms. Christel Cochez and Ms. Leen Wilmaerts, BEL, Belgian Ministry of Defence

BACKGROUND

A zoonosis is any infectious disease that can be transmitted from non-human animals to humans. Zoonoses are of military interest, because they are often emerging or even unrecognised diseases, or have increased virulence in populations lacking immunity. The easy access to these agents in nature is a serious problem for biological weapons proliferation and is increasing the probability of a serious bioterrorism incident. Concerted action for detection and surveillance is thus of importance, together with the dissemination of data and information between NATO partners.

> "Deployed troops are thus at risk of zoonotic diseases, and the risk of pathogen transfer from a deployment area to the nation of origin is also a concern."

OBJECTIVES

The first objective of HFM-230 was to define standards in the methods used to identify and detect viral and bacterial zoonose, both in the field and in the lab. The second objective was to review the outbreak alert and on-sight surveillance systems. Thirdly, HFM aimed to compile a list of pathogens that could serve as positive control or be used for validation purposes.

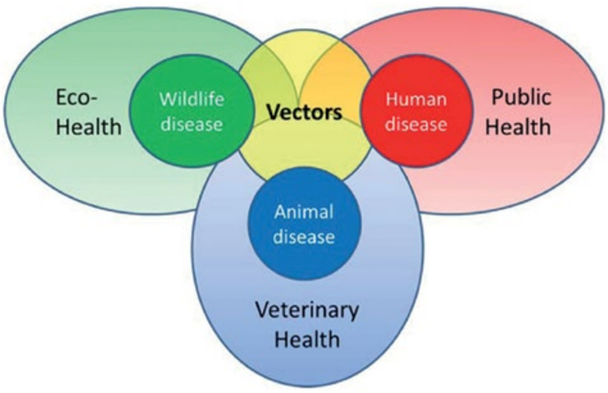

Figure 7: Zoonotic and vector-borne diseases impact on missions.

S&T ACHIEVEMENTS

A major outcome of the HFM-230 was the comprehensive collection of detection methods for the selected zoonotic and vector-borne pathogens. It delivered a living document that will require on-going revision by a future Research Task Group (RTG), as new diseases emerge and technologies improve.

SYNERGIES AND COMPLEMENTARITIES

HFM-230 was founded to summarise the scientific knowledge on the military impact of pathogens that are transmitted from animals to human, either by having an animal reservoir or from vectors such as insects, ticks etc. The RTG included over 17 representatives from 9 countries. It was headed by Belgium and included partners from the Czech Republic, France, Germany, Italy, Romania, Slovenia, Turkey and the United States of America.

EXPLOITATION AND IMPACT

HFM-230 developed a master priority list for vector-borne and zoonotic bacteria, parasites and viruses, with a first and second line detection. Finally, the group summarised the civil and military surveillance systems currently available, conducted a gap analysis and provided recommendations.

CONCLUSIONS

The potential of zoonotic and vector-borne diseases to impact the mission or to have increased virulence in populations lacking immunity make them of significant concern to military forces. Infectious diseases acquired in the operational zones continue to account for more military clinical visits than do battlefield injuries. In addition, it remains of concern to distinguish naturally occurring outbreaks of zoonotic and vector-borne diseases from intentional biologic attack is of concern. Concerted action for detection and surveillance, and subsequent dissemination of data and information between NATO partners is thus of importance. Moreover, decision makers are in need of tools to prioritise the pathogens of importance to military operations.

DIRECTED INFRARED COUNTERMEASURE (DIRCM) STATE OF THE ART AND FLIGHT TESTING METHODOLOGY (SCI-237)

Given the proliferation of Man-Portable Air Defence Systems (MANPADS) missiles, which are extremely widespread due to their low cost and small size, protection against Infrared (IR) threats is a high priority for NATO aircraft. Moreover, MANPADS missile seekers are using increasingly more sophisticated IR Counter-Countermeasures (IRCCM) which require aircraft Self-Defence Systems (SDS), currently based on flare dispensers, to be improved and/or replaced by new technologies. The laser-based Directed IRCM (DIRCM) system could offer a potential solution.

Mr. Tommy Sanders, USA, Naval Surface Warfare Center, Crane Division

BACKGROUND AND MILITARY RELEVANCE

This Research Task Group (RTG) supports the NATO Defence Against Terrorism (DAT) program by investigating large aircraft survivability against MANPADS. The RTG's work is aligned with the NATO Air Force Armaments Group (NAFAG) action 92/8. The NAFAG Aerospace Capability Group 3 Sub-group/2 (ACG3 SG/2) on Electronic Warfare (EW) self protection measures for joint services airborne assets submitted a request to the Science and Technology Organization (STO) in spring 2009 to study DIRCM technologies.

OBJECTIVES

The objectives of the study were as follows:

- conduct a DIRCM world market survey;
- develop a standardised test methodology for DIRCM systems in flight;
- summarise operational experience of the DIRCM systems;
- identify future DIRCM requirements for NATO's large aircraft.

S&T ACHIEVEMENTS

The RTG cataloged worldwide information on current and former DIRCM programs and established a standardised test methodology to assess DIRCM systems.

> "Globally connected terrorism transcends borders and continues to become more sophisticated, more indiscriminate and more lethal."

SYNERGIES AND COMPLEMENTARITIES

The RTG leveraged the biannual NATO trial EMBOW to measure the effectiveness of DIRCM SDS against IR missile seekers (*i.e.*, reticle, rosette scan and imaging seekers). The EMBOW trials have been organised biannually since 1983. These trials, overseen by NAFAG ACG3 SG/2, center on the IR threat and alternate with their equivalent (MACE) for the Radio Frequency (RF) threat. EMBOW's aim is to pool ground-to-air resources to create a realistic IR environment in which to test, study and develop technical and tactical CMs that will be shared amongst NATO Allies.

Figure 8: C-130J aircraft.

EXPLOITATION AND IMPACT

RTG findings will be used toward shaping updates to the NATO Staff Requirements (NSR) document on DIRCM: the guideline for identifying DIRCM requirements for NATO aircraft. Furthemore, the Italian Air Force used the methodology developed by the RTG to test and evaluate a DIRCM system built by Elettronica on their C-130 aircraft. Additionly, the Spanish Air Force is working jointly with Indra to develop and assess their latest In-Shield DIRCM system.

CONCLUSIONS

The standard test methodology developed by the RTG allows NATO allies to compare the performance of newer DIRCM technologies with those that are more mature in order to assure nations establish a cost-effective program that still delivers the performance the warfighter deserves.

FUTURE ROTORCRAFT TECHNOLOGIES (AVT-ST-005)

The Specialist Team (ST) formed a focused effort to support the NATO Joint Capabilities Group Vertical Lift (JCGVL) sponsored by Next Generation Rotorcraft Capability Team of Experts (NGRC ToE). The ST provided rotorcraft technology input from across the NATO Science and Technology Organization (STO) to the ToE and also to the associated NATO Industrial Advisory Group (NIAG) Study Group 219.

Mr. Patrick Collins, GBR, UK MoD, Helicopters Operating Centre and Mr. John Preston, USA, Army, Aviation and Missile Research, Development and Engineering Center (AMRDEC)

BACKGROUND

The ST linked the NGRC ToE with the ongoing rotorcraft technology developments within NATO nations. A previous activity (AVT-245, Future Rotorcraft Requirements) identified common rotorcraft needs, replacement timeframe and opportunities for the NATO rotorcraft fleet. AVT-245 resulted in a recommendation for a multi-NATO organization effort to develop a strategy for the future of rotorcraft in NATO. This ST was established to provide the interface between that strategic activity and on-going technical activities within STO.

Figures 9 and 10: The United States Army's Advanced Vertical Takeoff and Landing effort could see flying demonstrations of a vertical lift helicopter as early as this year (2018). (Getty Images)

OBJECTIVES

The objectives were to deliver technology expertise to the NGRC ToE and NIAG Study Group 219 over its two-year duration and to provide awareness to STO of the ToE's activities.

S&T ACHIEVEMENTS

Seven areas of specific interest were identified and are documented in a technical report:

- active flight control systems;
- advanced avionic architectures;
- increased performance;
- human factors;
- materials/manufacturing;
- survivability;
- cost of ownership reduction.

The team also developed summary information of current and recent STO technology activities of relevance to the ToE and NIAG Study Group.

SYNERGIES AND COMPLEMENTARITIES

The ST drew upon expertise from across NATO nations to identify key technological activities enabling future rotorcraft capabilities. These technological areas were identified and summarised in the team's report. The effort also identified and organised relevant STO technologies into a single cross matrix.

EXPLOITATION AND IMPACT

The ST identified, scoped and characterised technologies relevant to future NATO rotorcraft capabilities. The ST co-chairs were members of the ToE and supported the NIAG Study Group as members of the Quick Reaction Team on an *ad hoc* basis.

> "We must continue to push implementation of the [Future Vertical Lift] Strategic Plan which will positively impact vertical lift aviation operations for the next 50-plus years. Absolutely, that is what [Joint Multi-Role] is all about. As we understand the demonstrated technologies and the opportunities for future technologies, that will feed the desired and reasonable capabilities and requirements for the potential FVL solutions."
> *– Dr. William Lewis, director, AMRDEC Aviation Development Directorate.*

CONCLUSIONS

The ST was the technical interface between the strategic effort for future NATO rotorcraft capability and multiple STO and national supporting technology activities.

HETEROGENEOUS TACTICAL NETWORKS – IMPROVING CONNECTIVITY AND NETWORK EFFICIENCY (IST-124)

IST-124 provided better understanding of the advantages and disadvantages of different models for network interoperability for the mobile tactical edge in different types of operations. It further developed a network emulation environment improving international research collaboration and helping reduce the time-to-market for research results.

Dr. Mariann Hauge, NOR, Forsvarets forskningsinstitutt (FFI)

BACKGROUND

The number of different mobile networks present in a coalition operation is increasing. No clear guidelines exist on how to connect these networks to form a heterogeneous coalition network at the tactical edge to support interoperability and improve the overall network robustness and availability.

OBJECTIVE

Provide architectural and design guidance for tactical heterogeneous networks at the mobile tactical edge in order to support coalition interoperability and achieve more reliable and predictable network performance.

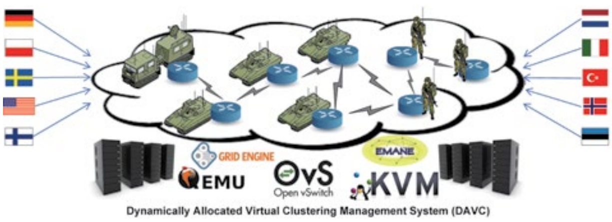

Figure 11: The figure illustrates the virtualised network emulation test-bed environment that has been developed by the group.

S&T ACHIEVEMENTS

IST-124 contributed to a better understanding (through analysis, simulation, emulation and expert opinions) on how to build interoperable heterogeneous networks at the tactical edge. A toolbox of design choices is proposed to help the network planner orchestrate the best design for a given operation. IST-124 identified necessary information exchange interfaces to enable heterogeneous coalition networking. Monitoring of three states of network health (normal, reduced, last effort) is proposed to improve resource management and service quality in the network. The group has demonstrated the benefit of having a cloud-based, shared and emulated network platform for doing joint experiments. The group produced four peer-reviewed publications, wrote a security architecture report and final report, held one demonstration and arranged two panel debates at conferences.

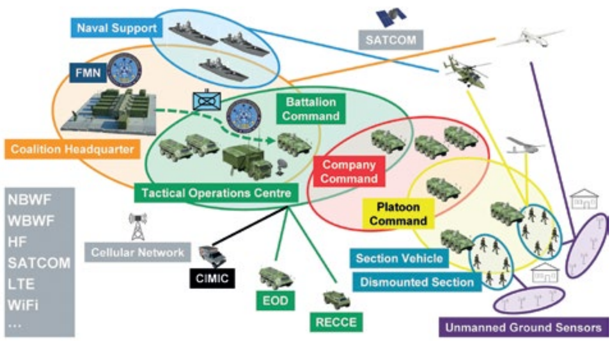

Figure 12: The Anglova scenario, highlighting challenges with coalition network interoperability at the mobile tactical edge.

SYNERGIES AND COMPLEMENTARITIES

IST-124 developed a test-bed that emulates the networks of the three-hour long Anglova scenario. The tools and scripts are made available to the public. Four other research groups are already using the environment. Expertise on transmission technologies, mobile networking protocols, security, quality of service, middleware, sensor networks and technologies for network virtualisation and emulation were shared by different stakeholders. The work was done synergistically with (national) ongoing projects.

EXPLOITATION AND IMPACT

Our effort to better understand the challenges involved when establishing mobile heterogeneous coalition networks at the tactical edge, identifying necessary information exchange interfaces, will help NATO nations to evolve/procure network equipment that can be interoperable. A well-connected network improves training, materiel and interoperability.

> "Good network connections improve training, materiel and interoperability."

CONCLUSIONS

Some guidance was given to improve interoperability at the tactical edge. Challenges imposed by different security architectures were identified. Knowledge and experience were shared through panel debates, demonstration, publications, presentations, reports and scripts and tools for the emulation environment.

INTEGRATED VIRTUAL NATO VEHICLE DEVELOPMENT (AVT-265)

Develop reliable and robust computational environments to evaluate complex existing or notional NATO vehicles for experimental studies, acquisition activities, acquisition planning, trade space, infrastructure assessment, and operational analyses.

Dr.-Ing. Michael Hönlinger, DEU, Krauss-Maffei Wegmann GmbH & Co. KG and Prof.-Dr. Roger L. King, USA, Mississippi State University

BACKGROUND

The use of validated physics-based modeling and simulation methods during the design and development of land, air, and sea vehicles is a critical enabler in the development of robust platforms that meet mission needs while avoiding high development costs. Early-program acquisition decisions are made in an environment where engineering data is at a minimum and the cost implications are at a maximum. To fully utilise physics-based models, a new design approach is needed that will allow the NATO nations to break out of the lengthy and expensive "build-test-fix" mode of development and implement a shorter more efficient "model-build-test" approach.

OBJECTIVE

The objective was the investigation of best practices used and concepts for benchmarking a Computational Based Engineering (CBE) approach for vehicle design and production for NATO that will contribute to an early detection of design flaws, a significant reduction in development time, more mission-suitable designs, and ultimately result in lower life cycle costs.

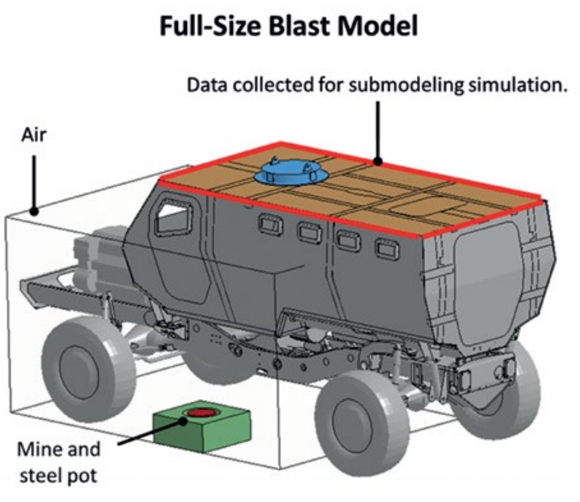

Figure 13: Numerical blast model of the vehicle and isolated region for submodeling simulation.

S&T ACHIEVEMENTS

Ideally, a vehicle can be developed computationally in a virtual space to meet all functional and performance requirements, thereby minimising the number of physical prototypes that need to be built and evaluated. Finally, this will increase affordability and flexibility of future military vehicle in NATO nations.

SYNERGIES AND COMPLEMENTARITIES

CBE provides a new design paradigm for NATO vehicles that will allow the NATO nations to break out of the lengthy and expensive "build-test-fix" mode of development and implement a shorter more efficient "model-build-test" approach. For example, single papers showed how modelling can be used to reduce the cost of testing and how modelling can be used for trade-space analysis in design decisions or for determining vehicle spare requirements that may be required for expeditionary forces.

EXPLOITATION AND IMPACT

For future threat scenarios NATO vehicles must be rapidly upgraded or newly developed in the short term. An advanced CBE approach will contribute significantly to delivering the required capabilities. This work contributes to the long-term aspects of "Land Engagement Capability" and "Vehicle Mobility, Safety and Survivability".

> "In the future, NATO will benefit from affordable, advanced vehicle designs using a computational prototyping design paradigm to meet requirements for tactical and operational mobility with a sufficient level of protection and increased payload."

CONCUSION

Ultimately, this work led to strengthened confidence in the performance and use of CBE techniques leading to increased exploitation of these and the adoption of common approaches between Government and Industry and between different NATO nations.

INTEGRATION OF CBRN PHYSICAL PROTECTIVE MEASURES TO LESSEN THE BURDEN ON PERSONNEL (HFM-199)

HFM-199 addressed integrated CBRN protection strategies. They focused on outlining technologies that lower the burden on the individual by using a layered approach consisting of contamination avoidance, physical protection, hazard mitigation response, containment and recovery.

Dr. Charles Bass, USA, Defense Threat Reduction Agency

BACKGROUND

Participation in military operations is accompanied by the threat of exposure to Chemical, Biological, Radiological, and Nuclear (CBRN) agents. There will be greater focus towards consequence management *versus* general battlefield readiness. Doctrine is changing from "fighting dirty" to relocate, isolate the area and restore operations. The changing threat requires dual-use and integrated solutions, rather than unique dedicated CBRN defence capabilities. Also, casualty acceptance under these circumstances will be far less than when all-out CBRN warfare was anticipated during the Cold War. Today, occupational health regulations and standards of civilian will play a more predominant role.

OBJECTIVE

The objective was to address integrated CBRN protection strategies, with the focus on lowering the burden on the individual. In doing so, HFM-199 used a layered approach consisting of contamination avoidance, physical protection, hazard mitigation response, containment and recovery.

> "The need for enhanced protection and lowering the burden to the warfighter is expected to remain for the foreseeable future."

S&T ACHIEVEMENTS

The report outlined the active, passive and reactive protection technologies. The trends of sensor miniaturisation and network integration provide the warfighter greater flexibility on the battlefield to avoid contamination or quickly move out of contaminated areas. The technologies show a trend toward improved performance at lower burdens. The development of new materials and application of nanotechnology lead this trend. HFM-199 provided also a synopsis of technologies.

SYNERGIES AND COMPLEMENTARITIES

Overall, a total of 7 NATO Nations participated in this international effort to systematically collect information on integration of CBRN physical protective measures.

Figure 14: Integrated CBRN equipment.

EXPLOITATION AND IMPACT

An increased level of protection of military personnel under operational conditions will improve combat readiness and effectiveness, and therefore the probability of successful mission completion.

CONCLUSIONS

There are many new emerging technologies that will be able to contribute to enhanced warfighter safety related to CBRN risks and events, while reducing physiological burden. The challenge will be to build appropriate systems to use and balance all available options against the missions that are to be expected and planned. The need for enhanced protection and lowering the burden to the warfighter is expected to remain for the foreseeable future.

INTELLIGENCE EXPLOITATION OF SOCIAL MEDIA: EXPLOIT SOCIAL MEDIA BEFORE THE BULLETS FLY (SAS-IST-102)

Social Media (SM) continues to evolve and is now a powerful weapon in hybrid warfare. SAS-IST-102 studied the exploitation of SM for Intelligence (INT) in order to counter its effect. It examined monitoring, methods and algorithms, and covered sense-making, validity, veracity and bias, and deception. Finally, practical examples provided a guide to apply these findings within NATO.

Dr. Bruce Forrester, CAN, Defence Research and Development Canada

BACKGROUND

How do military organizations exploit SM? Understanding the complex nature and potential uses of SM is the starting point. Many signals exist within SM that precede enemy action. Intelligence can tap into the first phase of the Organise, Recruit, Plan, and Act cycle that is needed to carry out attacks. Gaining actionable INT during the "Organise" phase is the best place to intervene in potential violence–"before the bullets fly".

Figure 15: Typical propaganda type tweet. (Source Twitter, 2017.)

OBJECTIVE

Identify rational and effective ways of exploiting SM as a source for INT, and investigate potentially relevant methods and tools for INT.

S&T ACHIEVEMENTS

SAS-IST-102 defined SM uses for INT and differentiated SM from traditional Open-Source INT (OSINT) use. Using a design methodology, they conducted research through real-world exploitation of SM. They examined theoretical and methodological considerations, which produced a practical understanding of the nature of SM data and associated challenges. This allowed genuine progress as many nations went from having no knowledge to gaining an ability to produce actionable INT. The team communicated their results through numerous publications, conferences and presentations.

SYNERGIES AND COMPLEMENTARITIES

SAS-IST-102 created a strong synergy between OSINT practitioners and defence scientists, involving 2 STO panels, 17 NATO countries plus Sweden, and 5 NATO organizations. Understanding that all entities faced the same challenges with respect to SM exploitation and an authentic desire to share, the community grew together and reached an ability to use SM source for INT.

> "#Intelligence #Article5 – Is NATO ready to deal with modern warfare?"

EXPLOITATION AND IMPACT

Many NATO countries have built their SM INT policies and capabilities based on the work of this Research Task Groupe (RTG). Actionable INT reports and policy have already been produced by participating countries using the knowledge and experience of the RTG. The real world case studies along with the "how-to guide" on monitoring, filtering, collection, analysis and estimation will allow other partners to follow suit. Methods and techniques developed can also be used to monitor for and discover fake news, propaganda and deception.

CONCLUSIONS

SAS-IST-102 was the first team to study SM for INT exploitation. Together, practitioner and scientists unravelled the complexities and produced practical knowledge important to INT analysts. The results have already provided both NATO and the nations valuable tools and insight to build a SM exploitation capacity, and to improve their INT capabilities.

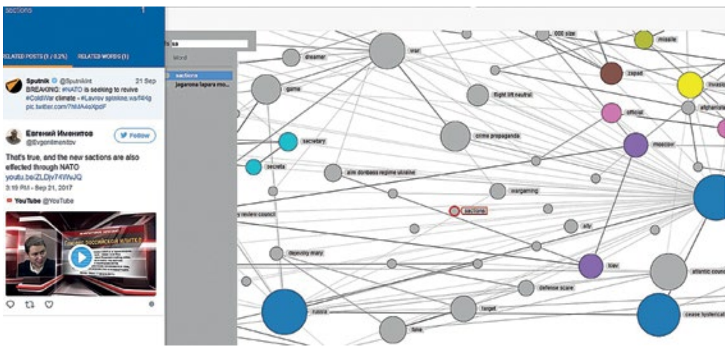

Figure 16: One tool for analysing tweets. (Source, Forrester B., 2017.)

A NEW REALITY: MODELLING & SIMULATION AS A SERVICE (MSG-136)

Modelling and Simulation (M&S) is a critical capability for the Alliance and its nations. As such, it is essential that M&S products, data and processes are conveniently accessible to a large number of users whenever and wherever required. M&S as a Service (MSaaS) combines service orientation and the provision of M&S applications via the as-a-service model of cloud computing to enable more composable simulation environments. These can in turn be deployed and executed on demand.

Dr. Robert Siegfried, DEU, aditerna GmbH and Mr. Tom Van den Berg, NLD, The Netherlands Organization for Applied Scientific Research (TNO)

BACKGROUND

NATO and nations use simulation environments for various purposes, such as training, mission rehearsal and decision support in acquisition processes. MSG-136 continued the excellent work of MSG-131 that initially defined "M&S as a Service" in the NATO context.

> "Modelling and Simulation has become a critical capability that should be available whenever and wherever required."

OBJECTIVE

To investigate, propose and evaluate standards, agreements, architectures, implementations and cost-benefit analysis of MSaaS approaches.

S&T ACHIEVEMENTS

MSG-136 defined the allied framework for MSaaS and provided experimental proofs of feasibility. Key deliverables included:

- operational concept of the allied framework for MSaaS;
- technical reference architecture (including service discovery, engineering process and experimentation documentation);
- governance policies;
- evaluation report providing evaluation results of the MSaaS concept.

In addition to developing the foundational concepts, MSG-136 conducted extensive experimentation activities to test and validate the concepts.

SYNERGIES AND COMPLEMENTARITIES

MSG-136 successfully brought together more than 120 subject matter experts from 16 nations (including partner nations Sweden and Australia) and 6 NATO bodies. MSG-136 conducted 10 face-to-face meetings and held more than 70 web meetings. The amount of work executed by MSG-136, the scope of topics addressed and the various deliverables would not have been possible without the extensive collaboration under the umbrella of the Science and Technology Organization (STO).

EXPLOITATION AND IMPACT

The efforts of MSG-136 were completed by an extensive outreach and dissemination program to inform stakeholders and decision makers around the world in government, industry and academia. Results and live demonstrations were presented at NATO CAX Forum, TIDE Sprint, I/ITSEC, ITEC, SISO events, and at national conferences. MSG-136 successfully organised a workshop at SimTecT to improve engagement of the Southeast Asia M&S community. A special issue of the *Journal of Defense Modeling and Simulation* was published and included MSaaS.

CONCLUSIONS

MSG-136 did ground breaking work by defining MSaaS in the NATO context and by developing operational, technical and governance concepts that permanently establish the "allied framework for MSaaS". In the spirit of NATO, MSG-136 excelled at "pooling and sharing" of M&S resources whereby all task group members contributed significant resources in relation to simulation systems, data sets, tools etc. for the benefit of the whole task group. Over its lifetime, MSG-136 was recognised as a global thought leader and pacemaker in this area.

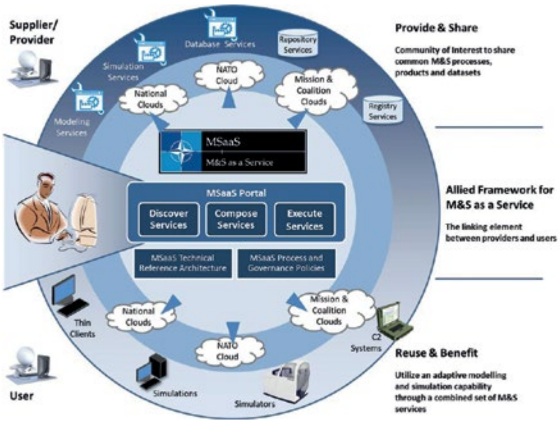

Figure 17: MSaaS Eco-System.

RELIABLE PREDICTION OF SEPARATED FLOW ONSET AND PROGRESSION FOR AIR AND SEA VEHICLES (AVT-183)

Aerospace and marine systems are becoming increasingly reliant on advanced numerical simulation for their design and development processes. Turbulent separated flows from smooth surfaces often restrict the effective use of Computational Fluid Dynamics (CFD) for accurate stability and control predictions, to a small region of the vehicle operating space. To improve understanding and enhanced CFD predictions, AVT-183 focused on one class of separated flows important to both air (Unmanned Combat Air Vehicle – UCAV) and sea (surface combatant) vehicles: smooth-surface separation from blunt leading edges.

Senior Research Engineer, Dr. James M. Luckring, USA, NASA LaRC and CFD Specialist, Okko J. Boelens, NLD, FEADSHIP – De Voogt Naval Architects B.V.

BACKGROUND

The ability to accurately predict smooth-surface separation effects could revolutionise the design process for military air and sea vehicles. The smooth-surface vortex separation from blunt leading edges is one instance known to cause adverse stability and control effects at maneuvering conditions. Enhanced understanding of this separation required new and focused experimental and numerical studies.

OBJECTIVES

The objectives of this activity were to conduct a series of aerodynamic and hydrodynamic experiments to obtain data for the onset and progression of blunt-leading-edge vortex separation and to use these data to improve CFD modelling for predictions of this flow.

S&T ACHIEVEMENTS

The combined experimental and numerical program of AVT-183 has established, for the first time, the structure of blunt-leading-edge vortex separation. When the onset of this separation was properly captured, CFD predicted the entire wing flowfield (air vehicles) and initial hull flowfield (sea vehicles), including attached and separated flows. An extensive experimental and numerical database now exists to further study this flow, and recommendations for future work were established.

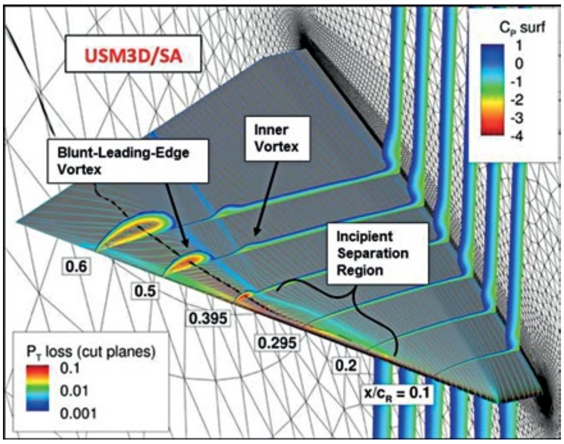

Figure 18: The structure of wing blunt-leading-edge vortex separation.

SYNERGIES AND COMPLEMENTARITIES

Eight experiments were completed among 5 NATO nations, and 17 different CFD methods have been used among 10 NATO nations to establisha significant benchmark. The Task Group submitted 39 scientific publications and the final NATO Technical Report (TR) was the largest published to date.

> "J.P. Slotnik *et al.*, "Advances in the physical modelling of turbulence for separated flows, transition, and combustion are critically needed to achieve the desired state of CFD in 2030," *CFD Vision 2030: A Path to Revolutionary Computational Aerosciences*, NASA CR-2014-218178."

EXPLOITATION AND IMPACT

Future air and sea military vehicles will increasingly rely on CFD simulation for part of their design. Advances in capability to predict smooth-surface separation effects will further enable simulation-based design activities. Accurate predictions of blunt-leading-edge vortex separation have been achieved, and the extensive database from AVT-183 could be exploited for future improvements to CFD predictive capabilities.

CONCLUSIONS

AVT-183 established improved predictive capability for blunt-leading-edge vortex separation effects that are relevant to stability and control concerns for both air and sea vehicles. Coupled with a database that guides future research, this information will further the development of CFD to enhance military vehicle design process.

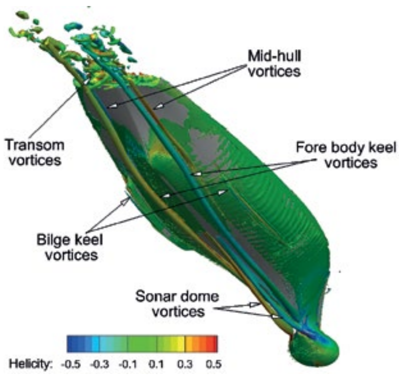

Figure 19: The structure of naval surface combatant cross-flow vortex separation.

SENSITIVE EQUIPMENT DECONTAMINATION (HFM-233)

Allied forces must be fully prepared to respond to and recover from the consequences of a Chemical, Biological, Radiological and Nuclear (CBRN) incident. In this context, an increasing amount of highly sensitive equipment has found its way into use within NATO forces. This study aims to support the operational specialist, as well as the force builder, when dealing with the issue of sensitive equipment decontamination. It describes today's situation and provides a glimpse into the intermediate future for the decontamination of sensitive equipment, using DOTMLPF-I.

Dr. Alexander Grabowski, DEU, Bundeswehr Research Institute for Protective Technologies

BACKGROUND

More and more mission-critical equipment, such as electronics, are not hardened against the effects of CBRN-weapons, rendering them useless after traditional decontamination. Hence, it is critical to ensure the availability of technologies capable to decontaminate such sensitive equipment. Rapidly evolving equipment technology requires an expert look into present and future capabilities in order to not let capability gaps emerge.

> "Potential aggressors will increasingly consider the use of CBRN weapons and devices as a viable means of asymmetrically countering NATO's military superiority."

OBJECTIVES

To support the capability-planner and -developer by providing an outlook on current and future technologies available and the challenges their fielding would provide on Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities, and Infrastructure (DOTMLPFI). This way, the materiel developer is in a position to develop requirement-tailored equipment in a timely and cost-effective manner.

S&T ACHIEVEMENTS

This study was a review and did not aim to produce new data. It collected, organised and managed scientific data to provide NATO's CBRN community with a comprehensive document that offers the information needed to identify existing and future capability gaps, and to appropriately close these gaps.

SYNERGIES AND COMPLEMENTARITIES

The synergies result from the cooperation of 9 NATO nations of the scientific, the materiel developers and the user communities. These synergies are clearly visible in the work of the Joint CBRN Defence Capability Development Group that emerged from the synthesis of these communities and initiated this study.

EXPLOITATION AND IMPACT

The outcome of this study is of high relevance to capability planners. It helps them decide which capability they should develop based on the accurate information their decisions will have on the whole spectrum of DOTMLPF-I. For example, this could inform whether there are additional budgetary requirements for the construction of facilities or special training requirements for the personnel who would execute this capability. This will contribute to deterring the use of Weapons of Mass Destruction such as area denial, obstruction of movement and reduction of physical performance.

CONCLUSIONS

This study, an outcome of the fusion of all communities in charge of CBRN-defence aspects in NATO, produced an extremely valuable tool allowing future threat- budget- and consequence-oriented capability planning.

Figure 20: Land vehicle decontamination.

ENHANCING INTEROPERABILITY AND AFFORDABILITY

The Alliance and its Partner Nations collectively work together to achieve and maintain peace, security, safety and stability in our neighbourhood. Working together in complex environments, while performing difficult tasks and operations within a multi-national coalition, requires a vast set of skills, knowledge and technology, including connected and interoperable forces. Furthermore, in times of economic downturn and austerity, coupled with the trend that military solutions tend to become ever-more expensive, affordability is all the more important.

NATO S&T provides support by providing solutions to enhancing interoperability and affordability. The following outline of STO activities is presented in this context:

- Cognitive Radio Networks (IST 140)
- Environmental Toxicology of Blast Exposures- Injury Metrics, Modelling, Methods and Standards (HFM-234)
- Incremental Implementation of NATO MTDS (MSG-128)
- Interoperability & Networking of Disparate Sensors and Platforms for ISR Applications (SET-218)
- Machine Learning Techniques for Autonomous Computer Generated Entities (IST-121)
- Method for Architecture Definition and Evaluation (IST-130)
- NATO Distributed Simulation Architecture & Design, Compliance Testing and Certification (MSG-134)
- Risk Analysis of Acquisition Programs (SAS-109)
- Risk-Based Framework for Strategic Planning (SAS-093)
- Collaborative autonomy for MCM
- Deep learning for MCM image classification
- Planning and evaluation for autonomous mine countermeasures
- Operational experimentation with the standing NATO maritime groups
- Exercise Dynamic Monarch 2017: Employing NATO’s new digital underwater communication standard for Submarine Rescue
- Deployment of ASW decision support during DYNAMIC MONGOOSE 2017 and asw-operational deployment of concepts 2017
- Vessel destination estimation under uncertainty
- Maritime situation awareness table top exercise (TTX)
- Adaptive multi-sensor/target tracking with belief propagation method
- Hydrophone equipped underwater gliders for wide angle seabed bottom loss measurement
- Source localization using underwater glider fleet
- Improved persistence for autonomous underwater vehicles
- Modelling and simulation for autonomous systems

COGNITIVE RADIO NETWORKS – EFFICIENT SOLUTIONS FOR ROUTING, TOPOLOGY CONTROL, DATA TRANSPORT AND NETWORK MANAGEMENT (IST-140)

Cognitive Radio is a promising solution for the well-known problem of spectrum scarcity, as it autonomously identifies the optimal parameters (frequency, modulation, etc.) for a transmission. Cognitive Radio Networks (CRN) go one step further by, not only adapting the low-level transmission parameters between two devices, but also by networking aspects (such as routing, topology control and data transport) in order to achieve end-to-end goals. Based on this technology, robustness and efficiency of military communications can be improved.

Stefan Couturier, DEU, Fraunhofer FKIE

Military communication is currently in a transition towards full networking and aims to achieve information superiority. For that, information must be transmitted in a fast and secure way, even in unknown and hostile spectral environments. Therefore, radios need to be capable of intelligently adapting to this environment.

> "Cognitive Radio Networks are applicable in highly dynamic environments while pursuing end-to-end goals, leading to a robust and efficient communication."

OBJECTIVES

IST-140 investigated Cognitive Radio Network technology, a promising solution for achieving this adaptability. Solutions for routing, topology control, data transport, and network management in infrastructure-based and *ad-hoc* CRNs were explored, taking into account military requirements. This also included the exchange of control information between radios.

S&T ACHIEVEMENTS

The group identified military requirements and technical challenges for Cognitive Radio Network usage in joint and combined operations. It became obvious that optimisation in a CRN requires multi-lateral cognitive processing. Firstly, frequency information must be handled, and secondly, networking information must be taken into account. Additionally, two-fold reactions on changes in the environment are enabled; *e.g.*, a partial interference of a network can be counteracted by either changing the frequency or by re-routing the traffic *via* the non-interfered parts.

SYNERGIES AND COMPLEMENTARITIES

This group used results from IST-077 Cognitive Radio in NATO, IST-104 Cognitive Radio in NATO II and IST-124 Heterogeneous Tactical Networks.

EXPLOITATION AND IMPACT

IST-140 results provide insight for proposals that can be used for further research and a later specification and standardisation of a Cognitive Radio Networking waveform, usable in both joint and combined operations.

CONCLUSIONS

IST-140 targeted technical solutions for the networking layer in Cognitive Radio Networks with a focus on military applicability. The focus was on end-to-end efficiency taking into account both frequency and networking issues.

Figure 21: A chameleon looking in two directions and adapting itself to the environment.

ENVIRONMENTAL TOXICOLOGY OF BLAST EXPOSURES: INJURY METRICS, MODELLING, METHODS AND STANDARDS (HFM-234)

HFM-234 considered the current knowledge gaps that exist within blast injury research that use a toxicological approach to investiga blast effects on people.

Mr Michael Leggieri, Director, DoD Blast Injury Research Program Coordinating Office, US Army Medical Research and Materiel Command

BACKGROUND

Blast injury is a significant source of casualties in current NATO operations, and the spectrum of blast injuries and their consequences is broad. While HFM-207 (Blast Injury) provided an initial assessment of the current state of relevant interdisciplinary science, it considered how understanding and mitigating blast injury will require a specific NATO technical activity devoted to the "environmental toxicology of blast exposures".

OBJECTIVES

The objective was to consider the current knowledge gaps that exist within blast injury research that usef a toxicological approach to investigate blast effects on people. Additionally, to produce guidelines for blast injury research for 4 work packages:

- dictionary of blast injury terms;
- guidelines for conducting epidemiological studies on blast injury;
- guidelines for reproducing blast exposures in the laboratory;
- and guidelines for using animal models in blast injury research.

S&T ACHIEVEMENTS

The Technical Team initiated their efforts by identifying a toxicology framework to understand the dose, mechanism of delivery of the dosage, and doseresponse endpoints of blast exposure, and then identified gaps within the framework. Based on the framework and specific gaps, HFM-234 developed a work program with the aim of providing guidelines for blast injury research for 4 work packages.

> "Furter research is needed on computational modelling of blast effects on humans."

SYNERGIES AND COMPLEMENTARITIES

Overall, a total of 10 NATO nations and 1 partner nation participated in this international effort to systematically collect information on environmental toxicology of blast exposures.

EXPLOITATION AND IMPACT

HFM-234 developed guidelines that can be used to provide experimental data necessary to develop and validate computational models of blast exposure. These will in turn elucidate the tissue-level mechanisms of injury necessary to guide the development and testing of effective protection systems for all NATO and their partner nations.

CONCLUSION

HFM-234 initiated dissemination of 4 work packages to the NATO nations and medical and health sciences community.

Figure 22: Mine explosion.

INCREMENTAL IMPLEMENTATION OF NATO MISSION TRAINING THROUGH DISTRIBUTED SIMULATION (MTDS) OPERATIONS (MSG-128)

NATO Airborne Warning and Control System (AWACS) and nations have a common need for training of air combined and joint collective tactical training, referred to in NATO as Mission Training through Distributed Simulation (MTDS). MTDS has achieved a level of maturity that makes it feasible for NATO to implement a persistent capability to support operational readiness.

Dr. Jean-Pierre Faye, FRA, Thales Air Operations

BACKGROUND

NATO member and partner nations operate closely together in real missions but have very limited live training opportunities for multinational operations. The aim of a networked capability within NATO and national simulators is to provide combat-like exercises to train and prepare coalition forces for multinational military operations.

OBJECTIVE

To open the door to a NATO MTDS capability by interconnecting NATO and national simulators and training centres. Interoperability standards, exercise set-up and management, briefing and after-action review processes, etc., all have to be established to initiate multinational exercises including Airborne Early Warning and fighter simulators.

> "Air warfare in a virtual environment could be done at lower cost than live training with more effective collective training."

S&T ACHIEVEMENTS

The MSG-128 Task Group defined the essential elements for a NATO MTDS environment. These included: concept of operations, operational requirements, architecture, standards, federation agreements, security aspects, network infrastructure and procedures for interoperability tests before operational exercises.

In support of this engineering activity, yearly experimental exercises have been performed, starting with small air-to-air missions using legacy simulators, such as: NATO E-3A Component (Geilenkirchen, E-3A); Volkel Air Base (Netherlands, F-16); German Air Force Simulation Control Centre (Cologne, mission operations centre and technical support); Airbus Defence and Space (Manching, Eurofighter); Air Operations COE (Rafale and Air C2 training cell); Canadian Forces Aerospace Warfare Center (Trenton, F-18) and Norwegian Defence Research Establishment (FFI, Kjeller, CRC).

Progressively the scenarios of exercises increased in complexity with air-to-ground missions and finally combined air operations. Simultaneously, the exercise environment transitioned incrementally towards the recommended standards and procedures of the MTDS infrastructure.

SYNERGIES AND COMPLEMENTARITIES

This activity was a collaborative effort of NATO AWACS and the nations to initially implement MTDS operations under the umbrella of Joint Capability Group-Command and Control (JCG C2) and the NATO Modelling and Simulation Group.

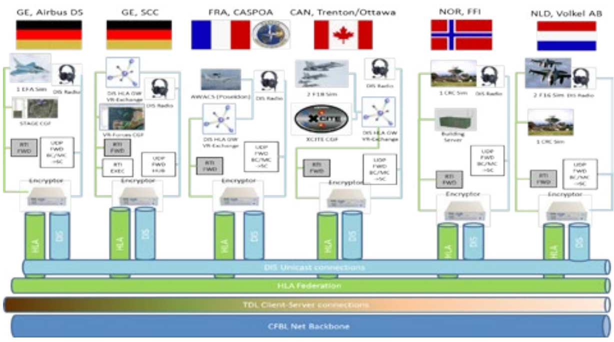

Figure 23: Distributed simulation architecture.

EXPLOITATION AND IMPACT

The aim of this activity was to provide air and joint tactical training capability, including Air C2, surface-to-air defence and Joint Intelligence, Surveillance, and Reconnaissance capabilities. In addition, MTDS can support mission rehearsals in coalition context, as well as experimentation with new systems before launching a development program.

CONCLUSIONS

The MSG-128 study demonstrated at a TRL-6 level the feasibility to federate heterogeneous operational training simulators in order to provide real NATO combat readiness training value. Fair fight conditions were sufficient to achieve training objectives with respect to interactions between all players. Remaining industrial effort is yet required for "mission proven" / "qualified" operational use (TRL 9).

The follow-on MSG-165 study aims to extend the MTDS capability and validate these on NATO/ multinational operational exercises and training events.

INTEROPERABILITY & NETWORKING OF DISPARATE SENSORS AND PLATFORMS FOR ISR APPLICATIONS (SET-218)

Around the world, NATO forces regularly conduct Intelligence, Surveillance and Reconnaissance (ISR) operations to support coalition missions. There is a need for international cooperation to address the lack of easy integration, interoperability and networking of disparate ISR sensor assets and sensing platforms for coalition operations such as force protection (e.g., base protection), Main Supply Route (MSR) monitoring and border site surveillance. The coalition missions are constantly changing, and there is thus a strong need within NATO to understand, share and work collectively together to develop NATO Standardisation Agreements (STANAGs) for coalition ISR interoperability.

Ms. Susan Toth, Co-Chair SET-218, USA, Army Research Laboratory

BACKGROUND AND MILITARY RELEVANCE

Future military operations require remote sensing systems to perform area surveillance and target acquisitions to avoid exposing NATO personnel to unnecessary threats. There exist substantial capabilities among the participating nations resulting in diverse and complementary ISR sensor assets, sensing platforms and technology. A Research Task Group (RTG) was needed to address the lack of easy integration, interoperability and networking of disparate ISR sensors and sensing platforms for coalition operations. There was a need within NATO to understand, share and work to develop standards for coalition ISR "plug-n-play" interoperability.

OBJECTIVES

The primary objectives were:

- To conduct joint research, development and experimentation of interoperable technologies leveraging disparate ISR sensors, systems, platforms and architectures from different nations;
- To develop proposed NATO STANAGs for ease of integration and interoperability of disparate ISR assets.

S&T ACHIEVEMENTS

This group developed a community of interest within NATO that enabled collaboration and understanding of individual nation's interoperability approaches, challenges and programs. Furthermore, SET-218 developed a common understanding of ISR sensor interoperability, made available the open standards, shared and exchanged technical knowledge on ISR interoperability requirements (existing STANAGs) and participated in nationally sponsored demonstrations.

> "The integration of disparate coalition sensors with proven middleware solutions enables true interoperability."

SYNERGIES AND COMPLEMENTARITIES

SET-218 surveyed existing interoperability efforts across the panel nations. From this effort, middleware capabilities from the USA were identified as potential systems that nations could adopt to enable interoperability.

EXPLOITATION AND IMPACT

The integration of coalition sensors with proven solutions enables true interoperability. As such, exploitation solutions are able to ingest and view sensor data across the international spectrum, making such systems sensor agnostic. NATO teams can then use the "best of breed" of available sensors rather than relying solely on national tool kits.

CONCLUSIONS

With diminishing funding for new sensors, it is no longer sufficient to address ISR needs with newer and better sensors. Every partner nation faces the same question of resources. Hence, why should we be limited to those tools found in our individual national tool kits when simple software interfaces can share information across the enterprise with limited burden to the enterprise? We, simply, do not fight alone.

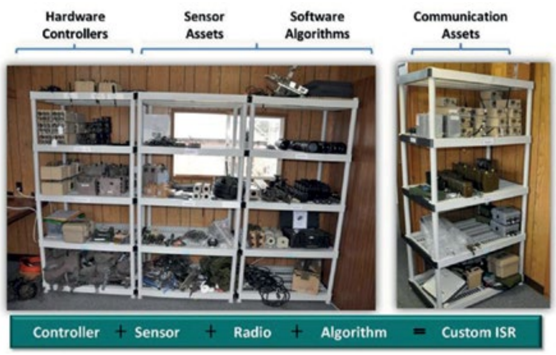

Figure 24: Examples of Sensor hardware and equipment.

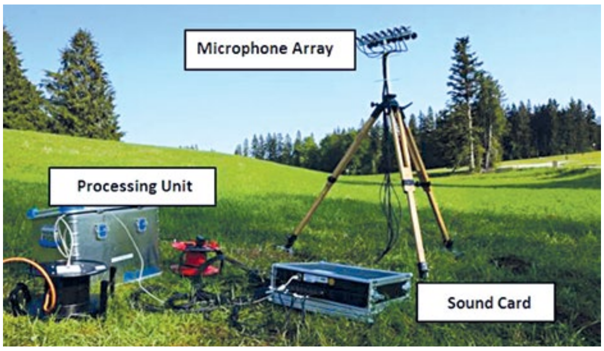

Figure 25: Microphone array and processing units.

MACHINE LEARNING TECHNIQUES FOR AUTONOMOUS COMPUTER GENERATED ENTITIES (IST-121)

The demand for more sophisticated Computer Generated Forces (CGFs) in simulation systems increases for the purpose of training and decision support. As behaviour complexity for CGFs rises, manual behaviour authoring techniques become unfeasible. This Research Task Group (RTG) explored the potential of using machine learning techniques to generate CGF behaviour models.

Dr. Jan Joris Roessingh, NDL, National Aerospace Laboratory and Dr. Joost Van Oijen, NDL, National Aerospace Laboratory

BACKGROUND

Autonomous Computer Generated Forces (CGFs) are abstractions of human individuals or aggregates within computer simulations. CGFs require human behaviour models in order to act autonomously. As the complexity of simulations grows, so does the need for more sophisticated CGFs. Traditional behaviour modelling techniques have difficulty meeting the requirements scaling of complexity. The use of machine learning as a method for generating (parts of) behaviour models could address this problem, but its potential has yet to be explored.

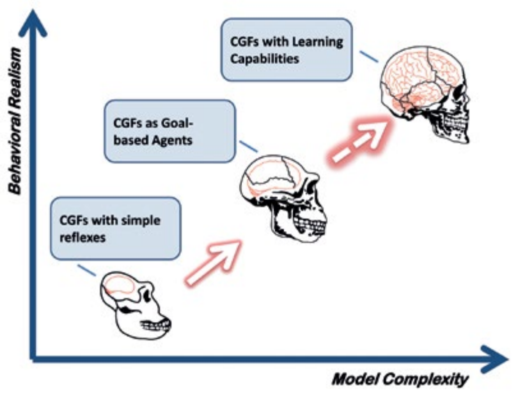

Figure 26: Various levels of Computer Generated Forces.

OBJECTIVES

The objectives of the RTG were to initiate guidance among researchers and developers when it comes to machine learning for CGF behaviour modelling, and review existing machine learning techniques and their (potential) applications to CGFs.

S&T ACHIEVEMENTS

The team conducted an analysis of stakeholders of CGFs (instructors, trainees, behaviour modellers, etc.) and their requirements with respect to the production (design, modelling) or consumption (interactions, employability) of CGFs. This analysis was used to chart the benefits (and potential drawbacks) for applying machine learning to fulfill these requirements. Valuable experiences and lessons learned from each member were documented in cases to illustrate different techniques in a varied range of application domains. Results have been shared through publications and special sessions at both military/industry-oriented and academic conferences.

SYNERGIES AND COMPLEMENTARITIES

This RTG consisted of members each with their own unique expertise of CGF modelling and machine learning, both from military/industry and academic perspectives. The exchange of the different viewpoints acquired through their national projects has made it possible to acquire a deeper, shared understanding of the potential uses of machine learning for CGFs. Insights from outside this RTG were obtained by organising special sessions at conferences. Cross-panel activities were conducted with MSG-127 (Reference Architecture for Human Behaviour Modelling in Military Training Applications).

EXPLOITATION AND IMPACT

The RTG produced valuable results for researchers, developers, training managers and scenario developers working with CGFs in the military domain. Guidelines, lessons learned and recommendations on the topic of applying machine learning techniques for CGF behaviour modelling have been documented, providing a better understanding of its potential benefits and drawbacks.

CONCLUSIONS

The use of machine learning for generating CGF behaviour models has shown potential for creating more sophisticated CGFs. Through automation, the burden of encoding valuable expert knowledge has shifted from subject matter experts and programmers to algorithms. Still there are many open issues that deserve further research, such as acquiring training data, transparency of models, validation and controllability.

> "Using machine learning techniques for generating computer generated forces (CGFs) behaviours will support faster building of training scenarios, more realistic simulations and require less effort to manage."

METHOD FOR ARCHITECTURE DEFINITION AND EVALUATION (IST-130)

NATO's Architecture Framework (NAF) is a means to facilitate secure acquisition, engineering and usage of interoperable, dependable and reliable systems. The Science and Technology Organization (STO) IST-130 provided version 4 of NAF (NAF V4) as a future Standardisation Agreement (STANAG), together with an architecture methodology.

Mr. Jean-Luc Garnier, FRA, Systems Engineering and Architecting Director, Thales

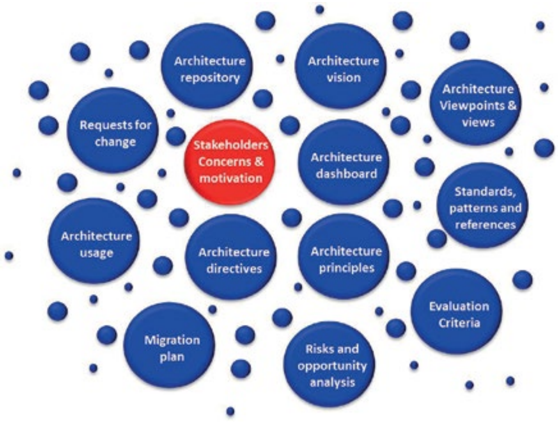

Figure 27: NATO Architecture Framework (NAF).

BACKGROUND

From the stand point of the decision maker and warfighter, there is a requirement to articulate operational needs, deliver affordable capabilities, and define smart defence scenarios and mission threads to meet current and future challenges in more complex and connected environments. Architectures enable Alliance strategies to properly support operations, development, acquisition and delivery of capabilities, reuse, deployment and disposal. In particular, Doctrine, Organization, Training, Material, Leadership, Personnel, Facilities and Interoperability (DOTMLPFI) elements can be formalised through architectures and shared between organizations to achieve interoperability.

OBJECTIVE

The objective of this group was to provide an updated NAF V4 as a future STANAG, including a methodology. This methodology extends traditional enterprise architecture approaches (beyond information and communication technologies) to support and enhance capability that is potentially far more complex and costly for governments and industries.

S&T ACHIEVEMENTS

The methodology benefits from a strong foundation, including a complete ontology and a bi-dimensional structure of views. It defined the main concepts for architecture principles and capabilities, a set of activities at enterprise and project level, including architecture landscape establishment, architecture vision, architecture description, architecture evaluation, migration planning, governance of architecture applications, architecture change decision and management of the architecture motivation.

Annexes include a complete example based on a search and rescue mission, usage of NAF V4, definition of viewpoints and selection of views.

SYNERGIES AND COMPLEMENTARITIES

IST-130 developed and coordinated NAF V4 with the Architecture Capability Team (ACaT). An experimentation phase involving NATO entities and national ministries of Defence provided feedbacks to improve this release. From a scientific point of view, the work of IST-130 is likely to be carried on by future Research Task Groups, namely on non-functional aspects of architectures.

EXPLOITATION AND IMPACT

Under governance enforced by the NATO Enterprise Architecture Policy, NAF V4 aimed to support the development of large complex programmes, like future C2 and Federated Mission Networks (FMN), addressing concerns throughout their lifecycle.

This architecture framework is expected to be used by major domains which started engaging with NAF.

> "NAF is a coherent way to architect systems that take into account constraints such as budget, schedule, safety, security and human factors."

CONCLUSION

With IST-130's work, the STO contributed significantly to improve the architecture activities coordinated by the ACaT. NAF V4 used to develop a strong foundation and methodology that makes it a credible candidate standard for NATO and externally. Experimentation and follow-on scientific studies can improve and reinforce the ability of NAF to become the indisputable architecture framework reference.

ENABLING DISTRIBUTED SIMULATION INTEROPERABILITY AND REUSE "NATO DISTRIBUTED SIMULATION ARCHITECTURE & DESIGN, COMPLIANCE TESTING AND CERTIFICATION" (MSG-134)

This activity covered the maintenance and update of: the NATO Education and Training Network (NETN), Federation Architecture and Federation Object Model (FOM) Design Document (FAFD), and the development of procedures and Integration Verification and Certification Tools (IVCT). It aimed to support compliance testing and certification of NETN FAFD compliant simulation components including certification of Standardisation Agreement (STANAG) 4603.

Mr. Horst Behner, DEU, Bundesamt für Ausrüstung, Informationstechnik und Nutzung der Bundeswehr (BAAINBw) and Mr. Jose Ruiz, FRA, Délégation générale de l'Armement (DGA)

BACKGROUND

Figure 28

The integration of distributed simulations and tools into interoperable federations is a complex and time-consuming task that requires extensive testing of individual components, interfaces and the integrated solutions. To support this task, NATO relies on un number of standards and agreements:

- the Allied Modelling and Simulation Publication AMSP-01, NATO Modelling and Simulation (M&S) standards profile, provides a list of recommended M&S related standards;
- NETN FAFD provides additional agreements on the use of standards to support distributed simulation;
- STANAG 4603 is one of the core standards for distributed simulation. Participating nations agree to utilise the High Level Architecture (HLA) compliance certification process established by the NATO Modelling and Simulation Group (NMSG).

The outdated HLA Federation Compliance Test Tool (FCTT) was developed by the United States of America (USA) and released to NATO in 2004. Since that time, the USA updated the FCTT but has been unable to release it due to export restrictions. Today, compliance testing needs to extend beyond the HLA interface and data exchange testing and address more complex federation agreements and requirements.

> "Standards, federation agreements, compliance test and certification are important tools that reduce integration risks, increase reuse of existing systems and support procurement of new interoperable simulation components."

OBJECTIVES

MSG-134 research delivers:

- maintenance and update of the NETN FAFD;
- the IVCT to support compliance testing and certification of NETN FAFD compliant simulation components including certification of STANAG 4603.

S&T ACHIEVEMENTS

For the IVCT, the following value propositions were recognised:

- improving federate tool quality;
- supporting federate certification;
- compliance label (scope of certification);
- federate integration assistance;
- federate validation assistance.

SYNERGIES AND COMPLEMENTARITIES

Both the collaboration and buy-in of stakeholders involved in NATO's distributed simulation are required to establish a service for simulation component interoperability certifications.

EXPLOITATION AND IMPACT

The use of IVCT will significantly reduce cost, risk and integration time for networked simulations. The interoperability, reliability and stability of distributed simulation systems will increase significantly. The NATO education and training community will rely heavily on IVCT as an up-to-date standard setter and certification tool.

CONCLUSIONS

Composing synthetic environments based on pre-tested and verified simulation components with certified interoperability capabilities reduces time, risk, and costs. At the same time, it maximises opportunities for reuse by stimulating use of standards-based interfaces for commercial and custom simulation components.

RISK ANALYSIS OF ACQUISITION PROGRAMS (SAS-109)

SAS-109 provides a collective understanding of risks for acquisition programs along with suitable analytical approaches for conducting cost, schedule, and performance risk analyses. This provides an understanding of the interdependencies across these different areas of acquisition risk to support the development of a trade space analysis framework.

Ms. Suzanne Singleton, USA, Army Materiel Systems Analysis Activity and Dr. Ahmed Ghanmi, CAN, Defence Research and Development Canada

BACKGROUND AND MILITARY RELEVANCE

In a time of tightening budgets, with operational requirements driving the need for accelerated acquisition schedules, international defence leadership needs an early, independent, and agile approach for assessing risk of acquisition programmes. Robust and standardised risk assessments can improve acquisition studies, better informing decision makers of potential risks, and provide insight to support trade space analysis, requirements development and cost growth control.

OBJECTIVES

SAS-109 had 3 objectives:

- develop a collective understanding of technical, schedule, cost, and operational risks for acquisition programs and related analytical approaches;
- develop improved data sources and estimation techniques and include best practices for data collection;
- develop a risk trade space analysis framework that links each of the individual analytical risk approaches.

> "It is the mark of an educated mind to rest satisfied with the degree of precision which the nature of the subject admits and not to seek exactness where only an approximation is possible." Aristotle.

S&T ACHIEVEMENTS

Various methods for conducting different types of risk analysis for acquisition programs currently exist and have been applied within nations, but the development of a framework that characterises interactions and interdependencies amongst these areas of acquisition risk for the purpose of exploring trade-offs was still in its early stages. SAS-109 developed a NATO risk assessment guidebook documenting the conceptual framework for risk and trade space analysis of defence acquisition programmes. It presents a common understanding of risk taxonomy and concepts, provides a comprehensive review of theoretical risk analysis methods, and identifies best of breed approaches for the assessment of schedule, cost, and performance risk. It also discusses state-of-the-art approaches for communicating and presenting the results to decision makers.

Figure 29: Assessing risk for acquisition programmes is critical for leadership to make informed decisions.

SYNERGIES AND COMPLEMENTARITIES

SAS-109 leveraged current national risk analysis methods from five countries and supported major national initiatives on risk methodology development and analysis applications for acquisition programs. SAS-109 leveraged previous SAS studies to integrate some life cycle cost concepts into the risk framework.

EXPLOITATION AND IMPACT

The guidebook will be used by NATO and NATO nations to improve defence acquisition studies, which will better inform defence leadership of potential risks and provide insight to support trade space analysis, requirements development and control of cost growth.

CONCLUSIONS

SAS-109's efforts will facilitate improvements in the area of acquisition analysis by providing best practice guidelines to evaluate acquisition risks and trade-offs regarding the cost, schedule, performance, and operational aspects of acquisition programmes.

RISK-BASED FRAMEWORK FOR STRATEGIC PLANNING (SAS-093-RTG)

Plans are nothing, planning is everything. The principal purpose of planning is to mitigate uncertainties that affect objectives. The risk-based framework developed by SAS-093 should help NATO and member countries better capture risks during the planning process and plan execution.

Dr. Slawomir Wesolkowski, CAN, Defence Research and Development Canada (DRDC)

BACKGROUND AND MILITARY RELEVANCE

Eisenhower once quipped "plans are nothing; planning is everything" and, according to von Moltke, "no plan survives contact with the enemy." This is because every strategic plan is saturated with risk: the effect of uncertainty on objectives. Risk can help you if properly managed, but can destroy you otherwise. Therefore, how can defence analysts help defence planners identify, evaluate and mitigate those risks to enhance strategic planning processes and make them more robust to uncertainty? In essence, how can we improve current planning processes to help create flexible and adaptable plans so that our forces can prevail in future conflicts?

OBJECTIVE

To develop a risk-based framework to complement strategic (long term) defence planning for NATO and member nations, providing a guide for how risk management can be systematically integrated into defence planning processes.

S&T ACHIEVEMENTS

SAS-093's proposed framework helps analysts systematically integrate risk management within a variety of strategic planning processes. The team outlined the ISO 31000 risk management process, emphasising the definition of risk: the effect of uncertainty on objectives. They then examined analytical support to strategic planning from the analyst's point of view: the analyst ensures the analysis (and risk management) carried out in support of a planning process is valid, verifiable, consistent, credible, transparent and rigorous.

The risk-based framework is divided into two parts: outlining the risk management framework and its application. The guide provides a high level framework of how to apply risk management to the analytical support to strategic planning within NATO and its nations. A case study on the United Kingdom's National Risk Assessment (NRA) outlines how the framework can be applied. Five additional framework applications, including one on the NATO Defence Planning Process (NDPP), are provided in a companion report.

> "Paraphrasing Theodore Roosevelt: risk is like fire, if managed it will help you; if not managed it will destroy you."

SYNERGIES AND COMPLEMENTARITIES

Similarities between NATO's, Norwegian and Canadian planning processes and between the United Kingdom's NRA and Poland's national security strategic review provided a common ground for developing a clear understanding of ISO 31000 and developing the framework. In addition to scientists assigned by participating nations, Canada provided funds for contracted work, while Norway and the United Kingdom provided teleconferencing.

EXPLOITATION AND IMPACT

The risk-based guide is intended for use by defence analysts supporting strategic defence planning processes. It will facilitate the systematic and explicit integration of risk management practices throughout strategic planning to improve both the processes themselves and the resulting plans.

CONCLUSIONS

Systematically integrating risk management within strategic planning processes should make those processes more robust to future uncertainty.

Figure 30: Communication is very important when talking risk.

COLLABORATIVE AUTONOMY FOR MINE COUNTERMEASURES (MCM)

Ongoing developments at the Centre for Maritime Research and Experimentation (CMRE) are focused on solutions for collaborative mission execution between autonomous systems, realised in experimentation and standardisation efforts of 2017.

Mr. Thomas Furfaro and Dr. Samantha Dugelay, STO-CMRE

BACKGROUND

Interoperability and collaboration between heterogeneous (in capability and origin) autonomous systems at sea is a significant gap in a joint operation of unmanned systems. CMRE's experience in applied autonomy research and standardisation places it well for providing common interfaces at the payload, system and squad levels of autonomous collaboration.

OBJECTIVES

The objectives are to define a standardised and generic collaborative autonomy framework which will enable a heterogeneous network of vehicles to self-organise autonomously in a jointly-allocated task. This allows use in multiple domains, the initial research being in a Mine Counter-Measure (MCM) context.

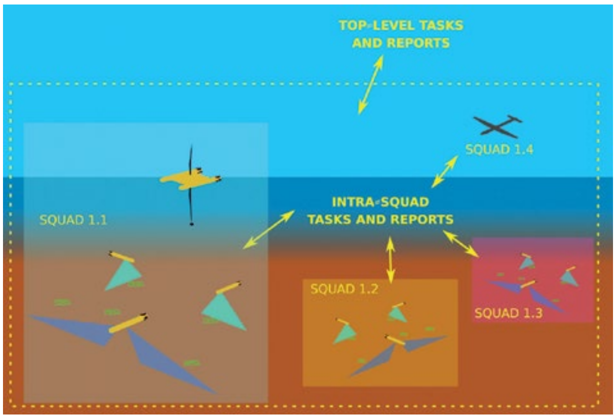

Figure 31: SCI-288-RTG aims to provide a standard tasking language for use in National or joint autonomy fleets composed of squads and sub-squads.

S&T ACHIEVEMENTS

The Distributed and Decoupled Collaborative Autonomy Framework (D^2-CAF) provides a framework for task allocation while separating the communication of task information from decomposition and execution. This allows for the algorithm-of-choice implemented to be deployed internally on participating nodes or to run in a "remote" mode where unmodified agents of opportunity may be wired in as collaborators *via* their native interfaces. Embedded versions of D^2-CAF were installed directly on autonomous platforms for MCM task allocation in a distributed manner in 2 experiments at sea. These new developments lend themselves to a more flexible deployment of task allocation strategies as a research approach, while also providing mechanisms for quickly integrating new systems into a collaborative fleet in an *ad hoc* manner.

> "Ongoing developments at CMRE are focused on solutions for collaborative mission execution between autonomous systems, realised in experimentation and standardisation efforts of 2017."

SYNERGIES AND COMPLEMENTARITIES

Concurrently, the project has participated in the Systems Concepts and Integration (SCI) Research Task Group 288, "Autonomy in Communications Limited Environments". It focused on the development of a common squad tasking approach that allows fleets of autonomous agents to be hierarchically composed and commanded at each layer in the structure, so that squads are task-capable entities available for allocation. Specifically anticipated is the inclusion of non-SCI-288 sub-squads, which may each expose their capabilities *en masse*, as a single unit. The design strategy has focused explicitly on domain agnosticism such that task dictionaries may be side-loaded into the tasking infrastructure to provide increased flexibility.

EXPLOITATION AND IMPACT

CMRE has participated annually in national and NATO mine-hunting exercises which demonstrate the capabilities of the D^2-CAF with CMRE vehicles and with partners of opportunity. The resulting framework will *in fine* allow for the integration of multiple national assets into a squad, and ease the interoperability between nations.

CONCLUSION

The Collaborative Autonomy for MCM (CA-MCM) project continues to demonstrate exciting examples of how the "full stack" of basic science, applied research and operational realities are dynamic interacting components that may be blended to provide future solutions for the nations and NATO as a whole. This includes work in fundamental questions at the cutting edge of maritime robotics, collaborative operations, and interoperability research.

This work was funded by Allied Command Transformation.

DEEP LEARNING FOR MCM IMAGE CLASSIFICATION

Autonomous platforms operating side-looking sonars are being deployed by National Mine CounterMeasures (MCM) forces to perform wide-area search, detection and classification. The Centre for Maritime Research and Experimentation (CMRE) has developed leading-edge Deep Learning (DL) Automatic Target Recognition (ATR) to ease the load of the operator in detecting and classifying mines.

Dr. David Williams and Dr. Samantha Dugelay, STO-CMRE

BACKGROUND

Traditional shallow classifiers which depend on manually defined features hit a performance plateau beyond which point more data doesn't improve performance. Conversely, DL, which falls under the machine learning/artificial intelligence category of algorithms, continues to improve as the number of data increases, operates directly on the sonar image without the need for pre-defined features and automatically learns the most useful information.

OBJECTIVES

The purpose of the DL ATR is to demonstrate the novel use of machine intelligence approaches for MCM, outperform conventional classifiers and provide an automated support to operators in mission and in the post-mission analysis.

S&T ACHIEVEMENTS

A complete development of a DL ATR has been achieved, introducing novel training techniques, utilising the high-resolution synthetic aperture sonar "big data" set acquired by CMRE over the past ten years, and adopting an ensemble approach of multiple DL classifiers to benefit from orthogonality of false alarms. Performance assessment of the DL ATR has shown a game-changing improvement in the correct classification of targets and huge decrease in false alarm rate as shown in figure 31. The DL ATR has also transitioned on-board the CMRE Mine-hunting UUV for shallow-water covert littoral expeditions (MUSCLE) vehicle to perform classification of targets in real-time in mission with a Graphics Processing Unit (GPU).

SYNERGIES AND COMPLEMENTARITIES

The advance of novel machine intelligence enables nations to develop operational tactics and endorse the use of Autonomous Underwater Vehicles (AUVs) and automated processing. CMRE is actively working with nations and national industries to transition the DL approach to multiple types of sonar sensors and assess the performance of the classifier in national and NATO mine-hunting exercises.

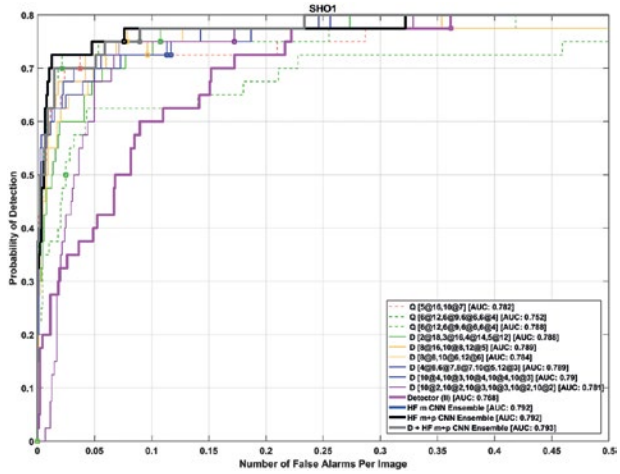

Figure 32: Example of a classification performance ROC curve *vs* false alarm rate. The pink curve corresponds to a conventional shallow classifier; the bold black curve is the ensemble DL ATR; the other curves correspond to multiple single DL ATRs.

EXPLOITATION AND IMPACT

CMRE is perfectly positioned to enable the transition of DL ATR into operational service for national de-risking and procurement. The impact of this research will allow easing an operator's effort to analyse the huge amount of data acquired during MCM missions, provide consistency of results and predictable performance of the classification rate as a function of the environment.

CONCLUSION

A novel DL ATR algorithm for sonar image classification has been developed from a novel training method and an ensemble approach to maximise the probability of correct classification whilst dramatically reducing the false alarm rate. Future work will focus on transfer learning for other sensors such as low-frequency synthetic aperture sonar and for other target concepts such as Unexploded Ordnance (UXO).

This work was funded by Allied Command Transformation.

PLANNING AND EVALUATION FOR AUTONOMOUS MINE COUNTERMEASURES

Autonomous platforms utilising side-looking sonars are being procured by national Mine CounterMeasures (MCM) forces. These systems can offer improved mine-hunting performance over that of current Mine CounterMeasures Vessels (MCMVs). However, the required planning and evaluation doctrine does not yet exist and hinders the uptake of these platforms.

Mr. Christopher Strode and Dr. Bart Gips, STO-CMRE

BACKGROUND

On completion of an MCM mission the mine-hunting platform must report its evaluated clearance to allow planners to assess the risk to follow-on traffic and/or determine the need for additional mine mine-hunting effort. For an MCMV operating traditional forward looking sonar, the estimated clearance value is determined using standard NATO tools (*e.g.*, MCM expert). However these tools do not currently allow for the generation of a percentage clearance value for autonomous platforms employing modern side looking sonars.

OBJECTIVE

The planning and evaluation project seeks to address the lack of tools and algorithms to evaluate the performance of mine-hunting missions conducted by autonomous vehicles. The current research is developing a suite of algorithms able to provide a real-time map of predicted performance as a mine-hunting mission progresses. The algorithms are suitably generic such that they can consider varying probability of detection within each “look” and furthermore consider the correlation when a vehicle conducts multiple overlapping looks. The framework seeks to estimate the instantaneous probability of detection as a function of a number of image quality metrics generated by the sensor itself – complexity, quality etc.

S&T ACHIEVEMENTS

A framework has been developed in which a number of algorithms may be tested in order to generate a continuously updated map (figure 32) of predicted performance. The resulting map accounts for multiple overlapping looks and the effects of varying probability of detection from image quality metrics generated by the sensor itself, such as quality and complexity. Additional algorithms may be used to extract the mine density and number of mines remaining from the resulting performance surface.

SYNERGIES AND COMPLEMENTARITIES

The development of a planning and evaluation framework for autonomous mine hunting will allow for the performance increase afforded by these vehicles to be fully exploited in military mine-hunting scenarios.

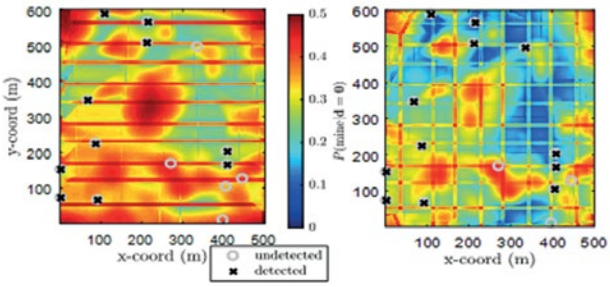

Figure 33: Examples of a simulated map showing the estimated residual risk–probability of an undetected mine being present–(left) after one horizontal pass of a lawnmower pattern, (right) after a second vertical pass.

EXPLOITATION AND IMPACT

The performance map may be further exploited within the CMRE autonomous collaborative framework, allowing additional Autonomous Underwater Vehicles (AUVs) to be directed to those regions requiring further mine-hunting efforts. Further work seeks to develop a prototype NATO planning tool in which mission parameters may be set with the performance map acting as the objective function.

CONCLUSIONS

A powerful framework has been developed allowing autonomous vehicles to evaluate ongoing mine-hunting mission performance. Future work will transition the algorithms towards a prototype planning and evaluation tool for autonomous MCM.

This work was funded by Allied Command Transformation.

OPERATIONAL EXPERIMENTATION WITH THE STANDING NATO MARITIME GROUPS

In 2017, the Centre for Maritime Research and Experimentation (CMRE) took two opportunities to showcase emerging technologies to the operational community and to validate them in an operational context.

Dr. Kevin LePage, STO-CMRE

BACKGROUND

CMRE has been fielding a multistatic network of autonomous underwater vehicles in Anti-Submarine Warfare (ASW) exercises since 2012. In 2017, the pace increased with the integration of the network into the exercise under "grey ship" tactical control during serialised events for the first time.

OBJECTIVE

The objective was to integrate CMRE's unmanned ASW network into tactical operations. This was achieved in exercise Dynamic Mongoose, when the ASW Coordinator was the Commanding Officer (CO) of a French frigate, during a dedicated period of operational experimentation, involving Turkish and Greek submarines, under the Tactical Control (TACON) of Commander, Standing NATO Maritime Group Two (SNMG2).

Figure 34: NRV Alliance with launch/recovery ramp and Greek SSK during ASW-ODC17.

S&T ACHIEVEMENTS

In order for the network to be deployed safely in the challenging environments of the North Atlantic and Eastern Mediterranean, a number of improvements were introduced. A launch and recovery ramp was developed and fitted to the NATO Research Vessel (NRV) *Alliance*, the vessel's endurance was increased to 48 hours (battery energy 18 kWh) and a deep water navigation capability was added. The unmanned platform positions are now displayed on the SNMG2 command systems.

"This has been of enormous value for our people. It has opened their minds to a vision of the future operating environment and has delivered a fabulous training opportunity for conventional ASW in challenging sonar conditions." Cdre. James Morley RN, COM SNMG2.

SYNERGIES AND COMPLEMENTARITIES

CMRE worked closely with Maritime Command (MARCOM), COMSNMG2, his staff, and the Greek and Turkish submarine squadrons to make the operational experimentation possible. Participation in DMON17 was arranged through close cooperation with COMSUBNATO and his staff. The CASW programme worked closely with CMRE's Maritime Intelligence, Surveillance and Reconnaissance (ISR) programme for the display of the unmanned asset positions on the command systems.

EXPLOITATION AND IMPACT

Maritime unmanned systems for ASW are gaining significant attention in NATO and the nations. In 2016, the CMRE worked with the NATO S&T community to generate the "Cost-effectively closing the NATO ASW Shortfall[1]" which lists 18 potential operational concepts and makes a series of recommendations on the utilisation of unmanned systems. In addition, CMRE has contributed to a paper on the vision for future NATO ASW where unmanned systems are highlighted as a promising emerging technology ripe for exploitation.

CONCLUSIONS

It is clear that unmanned systems are a promising emerging technology for future ASW. It is key that the nations combine to evaluate the feasibility.

This work was funded by Allied Command Transformation.

[1] AC/323-D(2016)0010-AS1 (INV).

EXERCISE DYNAMIC MONARCH 2017: EMPLOYING NATO'S NEW DIGITAL UNDERWATER COMMUNICATION STANDARD FOR SUBMARINE RESCUE

In 2017, the Centre for Maritime Research and Experimentation (CMRE) participated in the DYNAMIC MONARCH exercise for the first time, bringing to the operational players, a new digital underwater acoustic communications capability that may render escape and rescue operations more effective.

Mr. João Alves and Dr. Roberto Petroccia, STO-CMRE

BACKGROUND

After the establishment of JANUS as the first-ever standard for digital underwater communications, the development of scenarios of operational relevance was the next natural step. The prospect of employing JANUS for submarine rescue operations is very attractive. Currently, communications are by analogue underwater telephone, using the phonetic alphabet. This requires an operator who may be needed for other equally critical tasks. Stress and language biases may also play a part in the success of the phonetic exchange. By employing JANUS for rescue communications, the operator requirement can be removed with automated systems transmitting critical data, eliminating the human factors altogether.

OBJECTIVES

Figure 35: DYMH17, held in Turkey in September 2017.

The objectives were to expose new digital underwater capabilities introduced by JANUS to the operational community, gather feedback, and assess the applicability of such technology in submarine rescue operations.

S&T ACHIEVEMENTS

CMRE employed JANUS to deliver, in an automated way, vital submarine information (contents following the current rescue manual) from the Spanish Navy submarine *Tramontana* to the various "mother ships". Different communication scripts that are currently implemented using the underwater telephone (like POD and ventilation) were also passed successfully between the submarine and the surface using JANUS. Additionally, the protocol was used to transmit automatic identification system (AIS) contacts to the submarine and to establish a much-welcomed feature of chatting. This digital chat allows any conversation to be established pretty much in a cross-platform instant messaging style.

SYNERGIES AND COMPLEMENTARITIES

> "JANUS has become very useful to communicate with the mother ship (MOSHIP)." ESPS *Tramontana*.

CMRE developed a close relation with International Submarine Escape and Rescue Liaison Office (ISMERLO), Maritime Command (MARCOM), the SMER community and the nations participating in DYMH17. The Spanish Navy offered to install JANUS in the ESPS *Tramontana*, with the surface system fitted to ships from the Italian and Turkish Navies as well as on the ship hosting the NATO submarine rescue system.

EXPLOITATION AND IMPACT

JANUS opened the way for interoperable digital submarine rescue operations with potential for automated transmission of digitally encoded critical data without the need of an operator. In case of procedural communications (following operational scripts), JANUS can increase the efficiency and avoid phonetic bias introduced by the different languages. The exploitation impact of such a concept is immense, potentially leading to a disruptive look into current procedures and development of new doctrine.

> "Comms good; very useful information; no interference with voice UWC; the system has great potential and should be pursued." *The NATO Submarine Rescue System team*.

CONCLUSIONS

The introduction of interoperable underwater digital communications in the rescue scenarios opens the way for more effective operations where information is more rapidly and readily available and where personnel may not be required for data exchange, paving the ground for the seamless employment of unmanned vehicles.

This work was funded by Allied Command Transformation.

DEPLOYMENT OF ASW DECISION SUPPORT DURING DYNAMIC MONGOOSE 2017 AND ASW-OPERATIONAL DEPLOYMENT OF CONCEPTS 2017

This project assists the planning of the operations of both manned and unmanned Anti-Submarine Warfare (ASW) platforms. A number of tools and techniques may be applied to visualise expected performance and allow military operators and scientists to optimise platform dispositions. In 2017, a new decision support tool was demonstrated during 2 ASW deployments.

Mr. Chris Strode and Mr. Manlio Oddone, STO-CMRE

BACKGROUND

The Centre for Maritime Research and Experimentation (CMRE) had previously developed the Multistatic Tactical Planning Aid (MSTPA) software over a number of years. It has grown to become a highly flexible and powerful tool able to fulfil a number of roles including simulation, optimisation, and real-time decision support. However, the tool is overly complex and not suitable for use at sea on board military platforms. To that end a streamlined serviced based tool has been created, allowing operators to quickly plot georeferenced sonar coverage using only a standard web browser. This tool may be employed either stand alone or over a network using a server-client architecture. The latter providing the potential to operate over NATO networks to enable a standard acoustic prediction service.

OBJECTIVES

The project deployed to the NATO ASW Exercise Dynamic Mongoose (DMON) and to a trial with Standing NATO Maritime Group Two. During DMON, the tool was embarked in HNOMS Roald Amundsen. Its ease of use and ability to account for a range-dependent environment was greatly appreciated by those on-board. Developments in response to feedback included the generation of multiple predictions as a function of sensor depth allowing the best use of the ship's variable depth sonar. During the second trial, the bistatic performance of CMRE's autonomous underwater was predicted. Once again, sonar coverage was provided in near real-time allowing the adaptation of platform positions and depth in order to optimise target detection probability.

> "CMRE demonstrated software for predicting sonar ranges which has proven comprehensive, interactive and beneficial relative to current on-board software."
> *Commanding Officer*
> *HNoMS Roald Amundsen.*

S&T ACHIEVEMENTS

A powerful, service-based architecture providing range-dependent acoustic prediction has been developed and tested in a live exercise. The tool may be deployed over a network and can provide acoustic performance predictions for multiple heterogeneous assets with minimal operator input. The tool will enable the optimum disposition of all platforms in a task group.

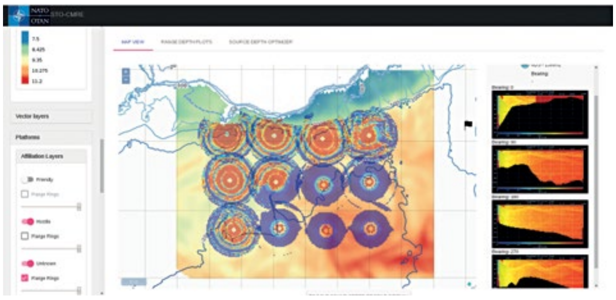

Figure 36: Planning tool output during DMON17.

SYNERGIES AND COMPLEMENTARITIES

The new tool has built upon the significant investment already made in MSTPA while providing a simple interface and novel networked architecture. The ability to run acoustic predictions on a powerful central server, while operators interact using only a web browser, presents a capability that could be employed on board any NATO platform. A consistent environmental forecast and acoustic model across heterogeneous assets deliver more realistic results.

EXPLOITATION AND IMPACT

The simple web-based interface may be easily expanded with additional layers to provide further optimisation and decision support. Such functionality may be added following feedback. The web interface will ensure that additional functionality does not create additional complexity.

CONCLUSIONS

The decision support project has developed an easy-to-use acoustic prediction tool that has been tested at sea during a NATO ASW exercise and operational experimentation. The tool was highly valued for its range-dependent predictions and ease of use.

This work was funded by Allied Command Transformation.

VESSEL DESTINATION ESTIMATION UNDER UNCERTAINTY

The effectiveness of maritime anomaly detection is highly dependent on the quality of information provided by a wide range of sources. The complementarity of various sources is exploited to estimate vessel destination while detecting possible suspicious behaviour on the basis of discrepancies observed. The solution allows representing reasoning under uncertainty from sensors and humans including their possible lack of reliability.

Dr. Nadia Ben Abdallah and Dr. Anne-Laure Jousselme, STO-CMRE

BACKGROUND

Accurate knowledge of a vessel's destination is required for maritime security and to optimise the efficiency of ports organization. Unfortunately, the Automatic Identification System (AIS) destination field is manually fed in and thus highly prone to errors. It is expected that a judicious combination of several complementary sources would improve the accuracy of the estimation of a vessel's destination.

> "Vessel destination estimation can be improved by the combination of information of independent sources, while their conflict may be an indicator of suspicious behaviour."

OBJECTIVES

There are two primary aims for this work, providing an estimation of vessels destination on the basis of several source's reports, while on the other hand, managing possible conflict between sources. The correlation of information from different sources allows estimating vessels destination in the absence of a valid AIS destination field, detecting possible suspicious behaviour in this respect, and reducing the false alarms in case of faulty sources.

S&T ACHIEVEMENTS

We proposed a general information fusion setting to estimate vessel destination through a flexible uncertainty model which:

- allows the combination of a variety of heterogeneous sources while accounting for their reliability;
- accounts for the different dimensions and sources of uncertainty;
- provides different information quality measures of uncertainty and inconsistency. The latter is used as an indicator of destination anomalies.

SYNERGIES AND COMPLEMENTARITIES

Participation in the NATO SAS-114 on assessment and communication of uncertainty in intelligence to support decision making facilitated the alignment of the uncertainty representation from human sources with the NATO-AJP-2.1 for intelligence procedure for Reliability, Credibility and Confidence.

EXPLOITATION AND IMPACT

The solution developed addresses 2 specific Maritime Situational Indicators (MSIs) of the Maritime Command (MARCOM) Maritime Situational Awareness (MSA) Direction and Guidance; MSI09-Vessel proceeding with course and speed inconsistent to reported next/last port of call or in a manner which is clearly uneconomic and MSI08-Vessel not transmitting AIS data or suspected of transmitting false AIS data based on discrepancies observed.

CONCLUSIONS

The solution demonstrated the ability to capture and process information of different natures, measure possible conflict between sources as an indicator of suspicious behaviour. The proposed framework can be instantiated to solve other specific problems involving various sources of information.

This work was funded by Allied Command Transformation.

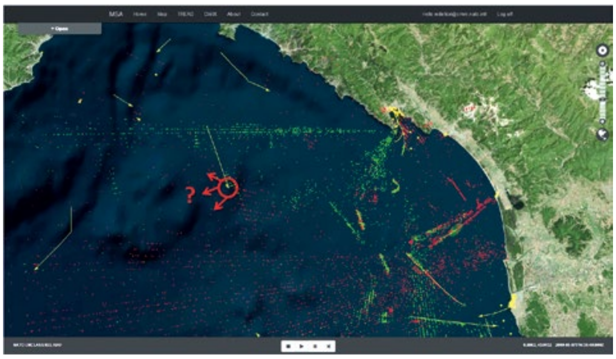

Figure 37: CMRE *Maritime Situation Awareness* (MSA) viewer displaying radar–red and green– and Automatic Indentification System (AIS)–yellow– tracks. Vessel destination (next port of call) is often unavailable.

MARITIME SITUATION AWARENESS TABLE TOP EXERCISE (TTX)

To capture different Maritime Situation Awareness (MSA) perspectives, NATO military staffs joined civilian stakeholders, including shipping companies, port authorities and maritime intelligence analysts, for a Table Top eXercise (TTX). Three concurrent games were played over three days, dissecting the NATO definition of MSA and addressing the topic of human belief assessment with imperfect information.

Mr. Jon Locke, Dr. Anne-Laure Jousselme and Mrs. Francesca de Rosa, STO-CMRE

BACKGROUND

It is appreciated that MSA is a multi-faceted and complex discipline and that approaches to MSA will be influenced by the specific goal or effect to be achieved. The Table Top eXercise (TTX) is a proven engaging methodology to elicit experts' knowledge, used previously at CMRE in particular to support harbour protection.

OBJECTIVES

The aims of the TTX were to provide expert based guidance for the development of MSA information systems, evaluation of NATO MSA doctrine and support research into decision making under uncertainty, further informing the focus of the efforts of the Science and Technology community.

S&T ACHIEVEMENTS

The TTX took the form of a number of games that sought to explore both the breadth and the depth of the topic. Two concurrent Matrix Games, each consisting 10 participants, ran for the duration of the exercise. The Matrix Game enabled participants to dissect the NATO definition for MSA and interpret the meaning and utility of key concepts contained therein: maritime environment, maritime situation, common understanding, and increased effectiveness in planning and conduct of operations. They were further asked to explore information needs when faced with a number of contemporary maritime situations (smuggling, piracy, terrorism and mass migration).

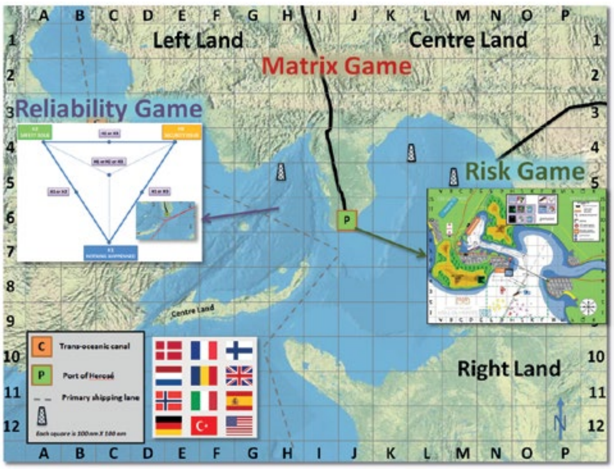

Figure 38: Board of the TTX games where a general scenario takes place, together with 2 specific vignettes.

The Risk Game and Reliability Game seek to better understand human decision making when confronted with uncertain information. The Risk Game focuses on imperfect information from a variety of sources, while the Reliability Game focuses on the impact of sources' quality on belief assessment.

> "Three concurrent games have been played dissecting the NATO definition of MSA and addressing the topic of human belief assessment with imperfect information."

SYNERGIES AND COMPLEMENTARITIES

The future developments of gaming methods for experts' knowledge elicitation would benefit greatly from the advanced NATO wargaming practices to be developed in the NATO SAS-139 on Analytical War Gaming, ensuring analytical rigour for improved support to decision making solution design.

EXPLOITATION AND IMPACT

Recommendations for goals and standards to support MSA have been derived from the Matrix Game results analysis. The methodology will be further refined and exploited to address challenges beyond the MSA domain.

CONCLUSIONS

An exit survey reported that participants judged the event to have been a success and a useful contribution to the wider understanding of MSA. Moreover, CMRE successfully validated the new Reliability Game as both an entertaining elicitation method and an efficient means to gather data linking the source quality and belief assessment.

This work was funded by Allied Command Transformation.

ADAPTIVE MULTISENSOR-MULTITARGET TRACKING WITH BELIEF PROPAGATION METHOD

A scalable and adaptive multisensor-multitarget tracking approach for maritime surveillance, which can adapt to different environmental conditions and can be developed by means of the efficient belief propagation method.

Dr. Giovanni Soldi, Dr. Domenico Gaglione, Mr. Leonardo Millefiori and Dr. Paolo Braca, STO-CMRE

BACKGROUND

Multisensor-multitarget tracking for maritime surveillance aims at estimating the position and velocity of moving targets by exploiting the measurements from multiple sensors, which can be corrupted by noise or false detections. This is usually modelled statistically when the parameters are known, but in real applications they may be unknown and time-varying, leading to performance degradation, unless a they can be estimated adaptively to avoid performance loss.

OBJECTIVE

The objective was to develop a Bayesian and self-tuning tracking system, based on the efficient Belief Propagation (BP) message passing scheme, to react and adapt to the changes in time of several unknown parameters, such as detection probabilities, target dynamic parameters and clutter intensity profile.

S&T ACHIEVEMENTS

The technique developed proved to be better suited than traditional methods in adapting to varying environmental conditions by means of several numerical simulations and by testing it in a real case scenario with measurements from 2 High-Frequency Surface Wave radar systems.

SYNERGIES AND COMPLEMENTARITIES

The adaptive multisensor-multitarget method was developed in close collaboration with the Massachusetts Institute of Technology (MIT). The algorithms will be a core component of a platform to be developed in the EC's RANGER project which will combine ground breaking radar technologies with innovative solutions for early warning. This warning will then be delivered to a surveillance platform for tracking as well as detection, recognition, tracking and identification of vessels far beyond existing legacy radar systems. This approach has been tested successfully in Anti-Submarine Warfare (ASW) scenarios using both multi-static Continuous Active Sonar (CAS) and Pulsed Active Sonar (PAS) developed at the Centre for Maritime Research and Experimentation (CMRE).

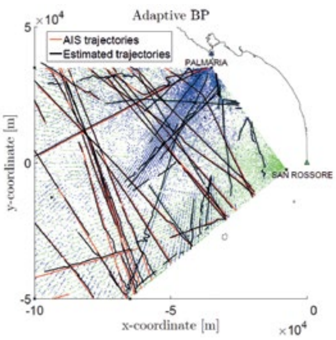

Figure 39: AIS trajectories (red) and those estimated by the adaptive proposed method (black) using measurements from 2 HFSW radars.

"A Bayesian self-tuning multitarget-multisensor tracking system with excellent scalability properties has been developed, which has the capability to react and adapt to the time fluctuations of several unknown parameters."

EXPLOITATION AND IMPACT

The adaptive multisensor-multitarget algorithm allows continuous estimation of several unknown parameters, such as detection probabilities and dynamic motion. It thus reduces the probability of missing a vessel of interest, during a sudden manoeuvre or a variation of the sensor detection probabilities, which, in traditional systems, are assumed constant and fixed. It is evident that many applications in maritime surveillance and situational awareness can benefit from this capability.

CONCLUSIONS

The Belief Propagation (BP) message passing scheme can be used to develop a Bayesian multisensor-multitarget tracking algorithm that is adaptive with respect to unknown model parameters. The BP approach provides a principled way to reduce complexity by exploiting conditional statistical independencies, which leads to quasi-optimum Bayesian multisensor-multitarget tracking algorithms with excellent scalability.
By exploiting the BP method, CMRE is also developing new algorithms for the data fusion of different sources (radars, Automatic Identification System [AIS]) that can be leveraged to enhance existing maritime surveillance systems.

This work was funded by Allied Command Transformation.

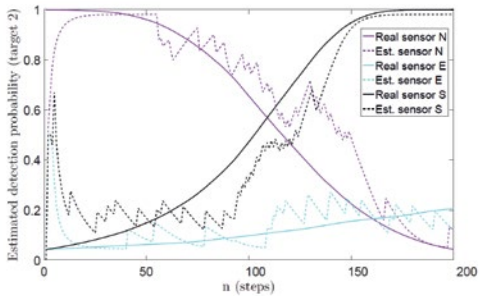

Figure 40: Estimated detection probabilities for a target at 3 different sensors in a simulated scenario. The solid lines indicate the true detection probabilities.

HYDROPHONE EQUIPPED UNDERWATER GLIDERS FOR WIDE ANGLE SEABED BOTTOM LOSS MEASUREMENT

CMRE participated in the United States Office of Naval Research (ONR)/ONRG sponsored "Seabed Characterisation Experiments 2017 (SBCEX'17)" to prove the concept of using acoustic payload equipped underwater gliders for characterising seabed geoacoustic properties.

Dr. Yong-Min Jiang, Mr. Bartolome Garau Pujol, Mr. Richard Stoner, Mr. Luigi Troiano and Dr. Daniele Cecchi, STO-CMRE

BACKGROUND

Seabed Geoacoustic Properties (SGP) have profound impact on sonar performance in littoral regions. Conventional techniques for determination of SGP, such as taking geophysical cores or remote sensing using acoustic source and receivers, often involve at least one ship and have to work in collaborative waters. Hence, they are time consuming and costly. One ongoing effort at Centre for Maritime Research and Experimentation (CMRE) is to develop seabed characterisation techniques using Acoustic payload equipped underwater Gliders (AGs) for future NATO capabilities of Battlespace Characterisation (BC) and Battlespace Preparation (BP) in denied or hostile littoral areas.

OBJECTIVE

CMRE participated in the SBCEX'17 in March 2017 through the ONRG funded "Glider with Acoustic Payloads for Seabed Characterisation" project. One of the CMRE objectives was to measure the wide-angle bottom loss (or bottom reflection coefficient) as a function of grazing angle and frequency use passive AGs.

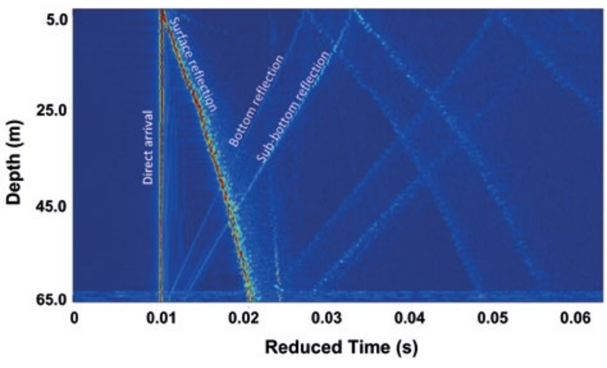

Figure 41: Wide angle bottom loss signals collected by a CMRE hydrophone equipped glider that can be used to determine the seabed reflection coefficients.

S&T ACHIEVEMENTS

Two CMRE passive AGs were brought to the SBCEX'17 sea trial. The acoustic payload for the gliders was developed and improved at CMRE. A broadband, wide angle bottom loss measurement technique was developed specifically for hydrophone equipped gliders. For the first time, the technique was successfully demonstrated at sea. Excellent quality data was collected, as shown in figure 40. The grazing angle range of the bottom loss that is critical for determining different sea floor types was obtained.

SYNERGIES AND COMPLEMENTARITIES

CMRE works closely with the partners of SBCEX'17, *i.e.*, 11 US institutes and 4 foreign institutes, on the data collected to estimate seabed geoacoustic properties, quantify uncertainty of the estimates, and then benchmark CMRE's novel approach against different seabed characterisation techniques.

EXPLOITATION AND IMPACT

CMRE is one of the front runners that transform conventional sea-floor characterisation techniques to underwater gliders. This work will enable further development of this bottom characterisation technique. By using glider fleets with active/ passive acoustic capabilities, it is expected to make future BP/BC missions in denied or hostile littoral areas possible in a cost-effective way.

CONCLUSIONS

The concept of characterising the seabed by measuring plane/spherical wave reflection coefficients at the sea bottom using a hydrophone equipped glider has been successfully demonstrated at sea. Immediate efforts include estimating SGP within a wide range of frequencies and setting requirements for future developments.

This work was funded by Allied Command Transformation.

SOURCE LOCALISATION USING UNDERWATER GLIDER FLEET

Analysis provided deeper understanding of the feasibility, as well as the engineering and ocean environmental knowledge requirements of using passive acoustic payload equipped glider fleet for localising underwater acoustic anomalies.

Dr. Yong-Min Jiang and Mr. Bartolome Garau Pujol, STO-CMRE

BACKGROUND

The Centre for Maritime Research and Experimentation (CMRE) has been exploiting the potential of passive acoustic payload equipped gliders for maritime Intelligence, Surveillance and Reconnaissance (ISR) missions. Three gliders have demonstrated the capability of using hydrophone/array equipped gliders for detecting underwater anomalous sound simultaneously during the “Glider sensors and payloads for tactical characterisation of the environment” sea trial in 2015. In the subsequent years, CMRE has been investigating the ability of this fleet of 3 gliders as a random distributed underwater acoustic network to localise the acoustic anomaly detected.

OBJECTIVES

The objectives were to assess the feasibility of using a fleet of hydrophone equipped gliders:

- to localise an underwater sound source;
- identify the necessary requirements;
- evaluate the impact of errors in conventional glider data and insufficient/incorrect knowledge of the ocean environment on the source localisation.

A subsequent outcome was to use the findings to set recommendations for glider payload improvement.

> “Networked passive acoustic underwater glider fleets are credible future solutions for persistent NATO maritime ISR missions in extended areas.”

S&T ACHIEVEMENTS

Both linearised and nonlinear travel time difference-based source localisation algorithms were developed, the former for implementation for future glider on-board processing in simple ocean environments. Comparison of the 2 algorithms using sea trial data reveals that nonlinear approach is more suitable for real-world scenarios. Furthermore, the linearised algorithm is used to quantify the uncertainty in source coordinates and depth estimates due to incorrect knowledge of the ocean environment, as well as errors in the times and positions of the glider fleet.

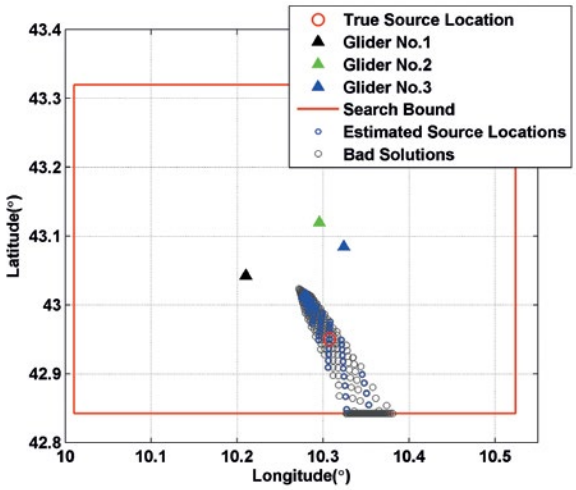

Figure 42: Search bounds, ground truth and estimated source positions due to travel time difference errors.

SYNERGIES AND COMPLEMENTARITIES

CMRE has played an important role in the development of novel sensing modalities/payloads for underwater gliders. NATO Allied Command for Transformation (ACT) funded this work which will inform all the NATO nations. The outcome of this study was presented in the workshop on “Military Applications of Underwater Glider Technology” hosted by CMRE.

EXPLOITATION AND IMPACT

Passive acoustic payload equipped underwater glider fleet has demonstrated the exceptional potential of extending maritime ISR coverage in littoral regions. Additional effort is recommended to unify the abilities of glider fleet and shore or grey-ship based glider control centre to advance the current research to future operational capability.

CONCLUSION

Gliders with hydrophone/array are inherently random distributed assets of an underwater network. Field data analysis shows that it is feasible to use a fleet of 3 gliders for detecting and localising an acoustic source if glider time synchronisation and navigation problems are properly addressed. Moreover, correct knowledge of ocean environment is essential for such kind of applications in littoral environments.

This work was funded by Allied Command Transformation.

IMPROVED PERSISTENCE FOR AUTONOMOUS UNDERWATER VEHICLES

Technology demonstrations where Autonomous Underwater Vehicles (AUV) optimise on-station time, energy replenishment and fast wireless underwater data hand-off with high degrees of autonomy and interoperability.

Dr. Vittorio Grandi, Dr. Alberto Grati, Dr. Alessandro Carta and Mr. Robert Been, STO-CMRE

BACKGROUND

The Centre for Maritime Research and Experimentation (CMRE) has developed a scalable design for a contactless battery recharging system based on Inductive Power Transfer (IPT) technology for AUV with a high level of interoperability. After implementing and testing for a 21-inch AUV, a module was built for a two-man portable AUV, the eFolaga. First tests of both the AUV and the docking station demonstrated the concept.

OBJECTIVES

The 2017 objectives included improvements to the existing docking station, the AUV's IPT module, and the autonomous docking algorithms developed in 2016. In addition, they showed the ability to tackle the persistency problem by delivering power underwater for a meaningful long duration scenario so extending on-station time beyond the battery capabilities.

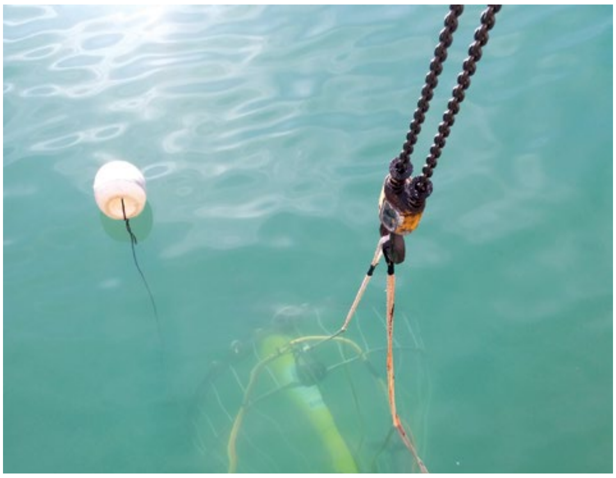

Figure 43: The AUV docked in the station during persistence trials in La Spezia.

S&T ACHIEVEMENTS

The AUV locking mechanism was simplified, made more robust, by going to a one-arm system. Autonomous docking was added as an autonomous behaviour to the open-architecture software suite, with an underwater navigation software module that enables accurate positioning–in the absence of an inertial navigation system–by communicating with buoys that have an Ultra-Short Baseline (USBL) capability. Both improvements enable the vehicle to stay underwater with cheap, highly accurate navigation. The vehicle can decide autonomously to pause the mission, dock autonomously and recharge its batteries while handing off the mission data *via* underwater Wi-Fi. Human intervention is minimised to problem-solving, triggered by AUV underwater acoustic communications. The four-year S&T effort to develop improved AUV persistence, including in-stride autonomous recharge and data hand-off, ended in 2017 with a very successful three-week period sea trial.

SYNERGIES AND COMPLEMENTARITIES

The IPT battery recharger and the underwater Wi-Fi capabilities have been integrated and are part of the sensor/capability suite with software modules and autonomous behaviours. These have been developed using CMRE architecture, aligned with the NATO Standardisation Agreement (STANAG) 4817 initiative on standards for multi-domain unmanned systems command and control, aiming at high levels of interoperability. This enables easy collaboration with others at CMRE such as the Underwater Network team in the field of USBL navigation, due to the high degree of interoperability of the AUV and buoys architectures and capabilities.

EXPLOITATION AND IMPACT

With the trials completing the project, findings have been disseminated to Allied Command Transformation (ACT). The project activities implement specific aspects of broader concepts generated for generic unmanned systems, providing important insights and opportunities for exploitation. Some NATO members have expressed interest in the project outcomes, and CMRE is now considering direct collaboration with them. Exploitation within the European Union (EDA, H2020) is being explored.

CONCLUSIONS

CMRE demonstrated the feasibility of a docking station for AUVs, providing AUV navigation assistance to homing, contactless battery recharging, and a high-speed underwater data link. The concept developed, showcased during a long-term mission in La Spezia harbour and designed with high degrees of scalability and interoperability, has proven to be highly successful.

This work was funded by Allied Command Transformation.

MODELLING AND SIMULATION FOR AUTONOMOUS SYSTEMS

CMRE has developed a standard based capability to support Modelling and Simulation, Verification and Validation, and Concept Development and Experimentation for autonomous systems.

Dr. Alberto Tremori, Dr. Arnau Carrera Viñas, Dr. Pilar Caamaño, Dr. Thomas Mansfield, Mr. David Solarna, Mr. Gianluca Maglione and Mr. Robert Been, STO-CMRE

BACKGROUND

The use of autonomous systems in real operations, in particular in the underwater domain, requires preliminary phases of testing–*Does it work?*–as well as experimentation and analysis–*How does it work?*–in accurate and realistic conditions and scenarios. Modelling and Simulation (M&S) at the Centre for Maritime Research and Experimentation (CMRE) has been supporting this concept since 2014, under the project "Persistent Autonomous Reconfigurable Capability (PARC)", funded by Head Quarters Supreme Allied Commander Transformation (HQ SACT).

OBJECTIVES

The overall goal of this activity is to bridge 3 different communities involved in the scope of the project:

- the M&S community as a facilitator and enabler for testing, Concept Development and Experimentation (CD&E);
- the Command, Control and Communications (C3) community;
- the robotics community as the subject of investigation.

A more specific objective for this work was the development of an architectural framework, based on simulation, for Verification and Validation (V&V) and CD&E for autonomous systems at sea.

A third objective was to develop a framework dedicated to supporting standard Verification, Validation and Accreditation (VV&A) procedures according to the specific needs of the PARC federation.

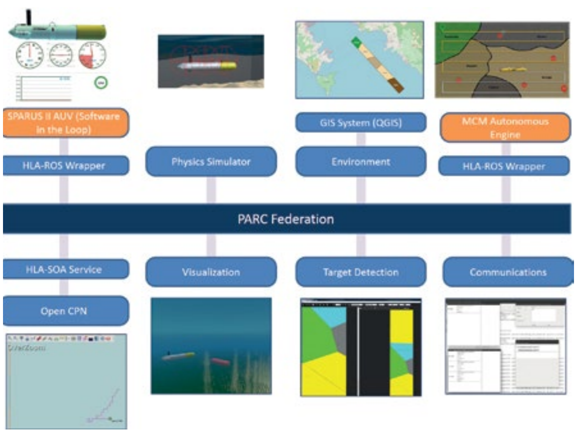

Figure 44: PARC Federation.

S&T ACHIEVEMENTS

The main achievement is the support to other warfare areas at CMRE, in particular the Collaborative Autonomous Mine CounterMeasures - (CAMCM) program where support was provided to verify and validate the algorithms for the underwater autonomous systems. Another achievement is the establishment of a capability to perform distributed over the Internet simulation. This provides CMRE with the ability to include multiple external stakeholders for the design, development, execution and experimentation of distributed simulations.

SYNERGIES AND COMPLEMENTARITIES

PARC is a project devoted to provide transversal support to different projects at CMRE. With the CAMCM programme, an intense collaboration has started and is proceeding, but the activities described in this report are also planned to support other programmes, such as the Cooperative Anti-Submarine Warfare. The availability of network architecture for enabling IoT (Internet of Things) distributed capability creates the framework for collaboration in NATO (NATO Modelling and Simulation Group – NMSG, Center of Excellence – COEs) and with nations.

EXPLOITATION AND IMPACT

This capability has been demonstrated during the Inter-service/Industry Training, Simulation and Education Conference (I/ITSEC), in November 2017 in Orlando. Demonstrations were provided at the NATO Science and Technology Organization (STO) booth and in the United States of America led Operation Blended Warrior (OBW) showcase during the multi-national presentation of exercise VIKING 2018. Further demonstrations will be performed during the execution phase of the exercise VIKING 2018 in April 2018 in Sweden.

CONCLUSIONS

Bringing together the 3 communities of robotics, M&S and C3 have seen the successful operation of hardware and software in the loop, C3 functionality and distributed simulation capabilities. This achievement, with the adoption and implementation of standards, specifically High Level Architecture (HLA) and Service-Oriented Architecture paradigm, are further pillars of this work that will allow further development and support to R&T activities for supporting NATO and nations.

This work was funded by Allied Command Transformation.

EXCELLENCE IN NATO SCIENCE AND TECHNOLOGY

Every year, during their Fall meeting, the NATO STB acknowledges excellence in S&T by awarding a Von Kármán medal in recognition of either a complete STO oeuvre or a single outstanding achievement, and awarding significant STO activities for scientific achievements.

In 2017, Dr. Fenner Milton was awarded the Von Kármán medal, Dr. Luc Vignaud was awarded an individual Scientific Achievement Award (SAA) and six STO activities received the awards for scientific achievement:

- Military Suicide Prevention (HFM 218)
- Analytical Support to the Development and Experimentation of NLW Concepts of Operation and Employment (SAS-094)
- Route Threat Detection and Clearance Technologies (SCI-256)
- Phenomenology and Exploitation of Thermal Hyperspectral Sensing (SET 190)
- Next Generation Autonomous Systems (NGAS) and Cooperative ASW (CASW)
- Development and Demonstration of Networked Autonomous ASW

EXCELLENCE IN NATO SCIENCE AND TECHNOLOGY

NATO recognises the value of S&T excellence within the Alliance. The quality of S&T, the breadth and depth of collaboration within NATO, and the potential impact and exploitation are the key elements for evaluating scientific activities and individuals for recognition.

Each year, the Science and Technology Board (STB) grants NATO S&T awards: the von Kármán Medal and the Scientific Achievement Award (SAA). These landmarks of excellence are granted when the STB considers that appropriate candidates were nominated. The NATO Chief Scientist, as Chair of the STB, ceremonially recognises the awardees during the STB meeting at the Fall.

The von Kármán Medal is the most prestigious scientific and technological award. It is an individual award that recognises contributions to the STO Collaborative Program of Work or a single outstanding Science and Technology Organization (STO) achievement of the laureate. Exemplary service and significant contribution to the enhancement of progress in S&T collaboration among NATO member and partner nations within the STO are key. The medal is presented together with an accompanying certificate signed by the STB Chair.

Scientific Achievement Awards were instituted in 1989 to recognise outstanding contributions in the context of activities in aerospace science and technology or aerospace systems applications. Under the STO, this outstanding tradition continues to reward the best of the best across the broader scope of the STO's technological mandate. Candidates or teams, proposed by the Collaboration Support Office (CSO) Panels and Group and the Centre for Maritime Research and Experimentation (CMRE), must have made significant contributions to S&T activities sponsored by the organization during the preceding four years. The SAA consists of a certificate signed by the STB Chair.

In 2017, during the Fall meeting in Berlin, Germany, the STB awarded one von Kármán Medal, one individual SAA and five group SAAs, which are summarised on the following pages.

THE 2017 VON KÁRMÁN MEDAL

Dr. Fenner Milton is a globally recognised leader and expert in electro-optical and infrared technology. Throughout his exemplary career, Dr Milton has made outstanding contributions to the development of electro-optical and infrared technology for the defence and security of the United States and its allies around the world. He has served in leadership of Science and Technology at the highest level within the United States Army, and has been a tremendous champion for the development of night vision sensing devices and systems. The results of his tireless advocacy of Science and Technology have made many positive impacts on NATO defence capabilities.

Dr. Milton has spent more than forty-five years in the night vision industry working for both private companies and the United States Government. At the Army's Night Vision and Electronic Sensors Directorate, he was responsible for the development of all aspects of electro-optical and infrared technology for the United States Army to include image intensifiers, infrared sensors, tactical lasers, counter-mine, counter-IED, and humanitarian de-mining technology. During his tenure, he placed a substantial emphasis on international collaboration in Science & Technology through his leadership positions on the NATO Sensors and Electronics Technology (SET) panel and the Technical Cooperation Program –Intelligence, Surveillance, Target Acquisition and Reconnaissance Group. In his previous role as Chief Scientist of the United States Army, he was responsible for its entire Science & Technology programme, which covered 21 different laboratories and RD&E centres; spanning approximately 10,000 scientists and engineers with a $1.4 billion annual budget.

As a true leader and scientific expert, Dr. Milton has bridged the gap from basic research to fielding capabilities, delivering critical enabling capabilities to Alliance forces, including systems such as Thermal Weapon Sight (TWS), Driver's Vision Enhancer (DVE), Enhanced Night Vision Goggle (ENVG) and others. In addition to delivering technologies, Dr. Milton is recognised for his creative approaches to develop innovative concepts for employment of new technologies. His vision, leadership and passion have directly contributed to saving lives and achieving mission success.

For his steadfast dedication and leadership within NATO Science & Technology and his remarkable contributions to the S&T Community, the STB recognised Dr. Milton for his exemplary work by presenting him with the 2017 von Kármán Medal.

Figure 45: Dr Fenner Milton receiving his medal from NATO Chief Scientist.

INDIVIDUAL SCIENTIFIC ACHIEVEMENT AWARD

As Chair of SET-163 on "Aspects of multi-parameter radar ATR in complex environments", Dr. Vignaud led the development and evaluation of radar automatic target recognition (ATR) techniques and capabilities for use in complex environments such as urban areas and harbours. He drew together knowledge from all the participating nations to provide a common characterisation of targets, environments and sensors, including their interactions, supported by simulations of radar reflections from the scene together with quantification of ATR performance.

In particular, Synthetic Aperture Radar (SAR) data sets from both satellites and airborne platforms were acquired of ships in and around the Oslo, Norway, harbour together with associated ground truth. This collaboratively collected data set provided essential underpinning to the development and assessment of tools and techniques within the SET-163 activity and will significantly benefit future collaborative activities.

ATR relies on having a database of example images of potential targets of interest. It can be prohibitively expensive or simply not feasible to gather all the real data required to produce such databases. A significant outcome from SET-163 was the demonstration of successful target recognition performance using a database constructed from simulations of target images acquired by electromagnetic predictions from 3D Computer-Aided Design (CAD) models. Another significant contribution was the demonstration of change detection between radar images obtained from different satellites operating at different resolutions and frequencies.

Radar ATR is essential for NATO's mission in terms of enabling effective combat identification in time-critical targeting scenarios and in terms of acquiring geospatial intelligence efficiently and effectively from the rapidly increasing number of strategic SAR platforms to which it has access. Radar ATR will also form a key aspect of future progress towards autonomous systems. The work and results from SET-163 have made a major contribution to meeting these NATO requirements.

Figure 46: Dr Luc Vignaud receiving his award from NATO Chief Scientist.

In recognition of his outstanding work and significant scientific contribution, the STB recognised and awarded the 2017 Science and Technology Scientific Achievement Award to Dr. Luc Vignaud, Chair of SET-163 on "Aspects of multi-parameter radar ATR in complex environments".

MILITARY SUICIDE PREVENTION (HFM-218)

HFM-218 is the first international working group striving to understand, scope and address the problem of military suicide across all NATO Member and Partner Nations.

Marjan Ghahramanlou-Holloway, USA, Ph.D., Associate Professor of Medical and Clinical Psychology, Psychiatry, Director of the Laboratory for the Treatment of Suicide-Related Ideation and Behavior, Uniformed Services University of the Health Sciences, Bethesda (MD)

BACKGROUND

Globally, suicide is the second leading cause of death among individuals between the ages of 15-29 years old (World Health Organization [WHO], 2014). Suicide remains a significant public health problem for the armed forces. NATO's evolving crisis management operations across various regions of the world require that increasing attention is paid to psychological fitness and effective strategies that provide timely and evidence-based practices to service members with suicidal intentions.

OBJECTIVE

The primary objective of HFM-218 was to foster an international collaboration across NATO Member and Partner Nations for the exchange of ideas and strategies for the prevention of military suicide.

Figure 47: Suicide remains a significant public health problem for the armed forces.

S&T ACHIEVEMENTS

HFM-218 designed a survey to collect epidemiological data on military suicide, as well as information on suicide prevention, intervention practices, and potential gaps. This systemic data collection, along with literature reviews, and concensus-building meetings among experts, led to recommendations for the development of standardised procedures, definitions, and systematic surveillance for documenting military suicides internationally. Moreover, a series of 9 papers on the following topics have been prepared for NATO leadership:

- military suicide prevention;
- role of leadership in suicide prevention;
- myths and facts on military suicide;
- technology-based suicide prevention;
- stigma and barriers to care;
- tactical level leadership;
- risk taking behaviours and suicide;
- military life stages;
- policy recommendations on military suicide.

SYNERGIES AND COMPLEMENTARITIES

Overall, a total of 14 NATO Nations and three Partner Nations participated in this international effort to systematically collect information on military suicide.

EXPLOITATION AND IMPACT

Military suicide prevention strategies, such as minimising stigma and barriers to care, and maximising leadership involvement in promoting timely help-seeking behaviours, will enhance mission readiness, unit morale/cohesion, psychological fitness, hopefulness, and personnel performance.

> "NATO, NATO Member and Partner Nations must take the next step in addressing military suicide."

CONCLUSIONS

According to the WHO, "suicides are preventable." The HFM-218 acknowledges the significant contributions of NATO leadership, service members themselves, and the military community in preventing suicides. The sharing of knowledge, best practices, and lessons learned across NATO Member, Partner, and contributing Nations is essential in taking an important next step in addressing the public health problem of military suicide.

ANALYTICAL SUPPORT TO THE DEVELOPMENT AND EXPERIMENTATION OF NON-LETHAL WEAPONS (NLW) CONCEPTS OF OPERATION AND EMPLOYMENT (SAS-094)

ISAF recommended "a 'deep dive' to identify non-lethal capabilities and options", as initial data showed 80-90% reductions in undesired outcomes (*i.e.,* own force casualties or civilian casualties [CIVCAS]) when Non-Lethal Weapons (NLW) were available. In response to this, SAS-094 analysed the future security environment to identify challenges across likely missions. It further developed 15 case studies and integrated subject matter expert input through a land-focused concept development assessment game, and a maritime-focused tabletop wargame and assessment of 2 NATO non-lethal technology exercises.

Col. Rey Masinsin, USA, USA Marine Corps, Director Joint Non-Lethal Weapons Directorate

BACKGROUND

NATO has had interest in Non-Lethal Weapons (NLW) for over a decade. In 1999, the North Atlantic Council signed the NATO NLW policy, defining NLW as "weapons which are explicitly designed and developed to incapacitate or repel personnel, with a low probability of fatality or permanent injury, or to disable equipment, with minimal undesired damage or impact on the environment."

It also identified NLW as a "critical, additional capability needed in order to meet the demands of future operations." Recent and ongoing operations have confirmed this need and further increased NATO interest as indicated by a report for the Commander of International Security Force Assistance Force (COMISAF) calling for a 'deep dive'.

> NLW are a "critical, additional capability needed in order to meet the demands of future operations."

OBJECTIVES

SAS-094's objectives were to support the development and experimentation of NATO and national NLW concepts of operations, employment and use.

Figure 48: Radio frequency (RF) vehicle stopper being used in NNTEX-16L.

S&T ACHIEVEMENTS

SAS-094 organised and completed the following activities:

- Future security environment assessment, resulting in the development and analysis of a set of representative scenarios;
- Examination of past operational experience, lessons learned, and existing concepts and doctrine, leading to 15 case studies;
- A concept development assessment game and a tabletop wargame to gain operational and technical subject matter expert judgments;
- Integration of quantitative and qualitative results from national utility exercises and assessments;
- Assessment and analysis support for 2 NATO Non-lethal Technology Exercises (NNTEX): one maritime and one land.

SYNERGIES AND COMPLEMENTARITIES

SAS-094 integrated national efforts with numerous NATO and non-NATO efforts to achieve their objectives: the 2 NNTEX exercises sponsored by NATO's Defence Against Terrorism Programme; NATO Army Armaments Group; European Defence Agency and European Union projects; and several NLW symposia.

EXPLOITATION AND IMPACT

SAS-094's research provides the Alliance with data-based analysis to support national NLW concept development and experimentation and allows for leveraging opportunities for NLW usage in many other areas (*e.g.*, with Ground Based Air Defence on counter-small unmanned aerial systems opportunities). Their analysis identified 6 areas where NLW contributions need to be integrated into NATO and national concepts.

CONCLUSIONS

SAS-094's innovative analysis allows for effective implementation of NLW within national operational concepts and doctrine, which will increase the overall operational effectiveness of NATO.

ROUTE THREAT DETECTION AND CLEARANCE TECHNOLOGIES (SCI-256)

The activity assessed the potential and limitations of new and emerging technologies for detecting route threats, such as landmines and Improvised Explosive Devices (IEDs). The Task Group (TG) investigations were based on setting up, conducting, analysing and reporting demonstrations, tests and trials of systems based on these technologies.

Dr. Arnold Schoolderman, NLD, Toegepast Natuurwetenschappelijk Onderzoek (TNO)

BACKGROUND AND MILITARY RELEVANCE

The threat by IEDs has become a high priority issue for NATO forces in the last decade. This class of weapons is accessible and affordable for terrorists and insurgents in NATO areas of operation. The use of IEDs is now so widespread that they have become a global and enduring threat. IEDs and other types of on- and off-route threats, such as landmines, restrict freedom of manoeuvre of NATO forces. In order to counter the route threat, the development of new countermeasures has began at governmental laboratories, universities and companies worldwide. These countermeasures aim to defeat the threat by focusing on different aspects such as detection, conformation and neutralisation, and are based on many different technologies. It is important to obtain information on the expected performance of the countermeasures under development and their suitability for deployment in military operations.

> "IEDs, the signature weapon of insurgent forces."

OBJECTIVE

The objective of the TG was to investigate the potential and limitations of new and emerging techniques for countering the on- and off-route threat (landmines, IEDs, emplaced explosive hazards).

S&T ACHIEVEMENTS

The TG conducted 3 demonstrations and trials:

- the first trial focused on experimental change detection systems on ground vehicles, using both visual cameras and Light Detection And Ranging (LiDAR);
- the second trial investigated non-linear junction detectors, both commercial hand-held devices and experimental vehicle mounted systems;
- the third trial demonstrated techniques and methods for the inspection of culverts in the presence of explosives.

SYNERGIES AND COMPLEMENTARITIES

Since the TG members represented major defence R&D organizations, this TG resulted in an active network contributing to several bi- and trilateral cooperations. Both the NATO Centre of Excellence Counter-IED and the Military Engineering Centre of Excellence have shown interest in the work of this TG.

EXPLOITATION AND IMPACT

The final products of the TG include information on the potential and limitations for several new and emerging technologies for the detection of route threat and recommendations on their suitability as detection tools in bothmounted and dismounted route clearance operations. These products can be used by defence research establishments in their R&D planning and procurement decision-making processes.

CONCLUSIONS

The TG produced 3 reports, one on each of the three demonstrations and trials. These reports contain descriptions of the technologies and devices that were investigated, descriptions of the demonstrations and trials, and a chapter on the observations by the TG on the potential and limitations of the technologies under investigation.

Figure 49: Experimental ground vehicle-based change detection systems.

PHENOMENOLOGY AND EXPLOITATION OF THERMAL HYPERSPECTRAL SENSING (SET-190 RTG)

During the past ten years, NATO countries actively involved in airborne thermal infrared hyperspectral sensing have expressed a strong interest to work together to create a high quality dataset that will serve as a benchmark for comparison.

Dr. Alexandre Jouan, CAN, Defence Research and Development Canada (DRDC)

BACKGROUND AND MILITARY RELEVANCE

SET-190 advanced the overall understanding of the phenomenology of thermal hyperspectral sensing with an emphasis on Intelligence, Surveillance and Reconnaissance (ISR) observables, and the detection of Chemical, Biological, Radiological (CBRNE) and Improvised Explosive Device (IED)-related threats relevant to defence applications. For the first time, multiple nations collaborated to better understand the physics of airborne thermal infrared hyperspectral sensing related to threat detection. The resulting dataset represents a unique and invaluable reference to benchmark current and future hyperspectral sensors.

> "This study allows for a better understanding of hyperspectral phenomenology which can lead to improved detection and identification of targets of vital interest to the military community."

OBJECTIVES

SET-190 was formed to address this long standing goal by preparing and conducting the Pronghorn campaign, completed in August 2014 at Defence Research and Development Canada (DRDC). The campaign focused on understanding the physics of airborne thermal infrared hyperspectral sensing related to ISR and CBRNE/IED threat detection.

S&T ACHIEVEMENTS

Each of the participating nations took a leadership role in the planning and execution of static or dynamic experiments. Experiments addressed the effect of the angular variation of source illumination and target reflectance/emissivity on the detection, indirect illumination and shadowing effects from nearby structures, change detection; gas and spills detection; detection of buried IED surrogates; unexploded ordnance (UXO) detection and rediscovery of moving vehicles. Dynamic experiments had to be meticulously coordinated with the airborne and ground-based technical teams, often under challenging weather conditions. Three aircraft were synchronised to carry the hyperspectral payloads, which included all available Commercial Off The Shelves (COTS) thermal systems, a well characterised United States-government thermal instrument and 2 reflective sensors.

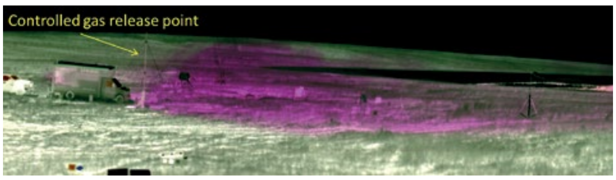

Figure 50: Three-band composite thermal image showing a gas release event in purple.

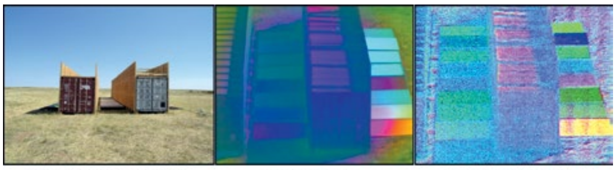

Figure 51: (from left to right) Indirect illumination site, 3-band MWIR image and composite image using 3 principal components of the thermal hyperspectral image.

SYNERGIES AND COMPLEMENTARITIES

During the Pronghorn campaign, nations shared their expertise, specialised instrumentation and deployed significant technical teams on the ground to support the operation.

EXPLOITATION AND IMPACT

Preliminary results for the detection and identification of a gas plume from a controlled release are shown in figure 49. An example of indirect illumination effects is shown in figure 50. Through a comprehensive exploitation of relevant data, SET-240 RTG (as a follow-on of SET-190) will provide recommendations on how these hyperspectral technology and datasets will enable the detection of CBRNE/IED threats.

CONCLUSIONS

The SET-190 RTG achieved its goal of generating a high quality thermal hyperspectral dataset that will provide the baseline for improving NATO ISR capabilities for CBRNE/IED threat detection.

DEVELOPMENT AND DEMONSTRATION OF NETWORKED AUTONOMOUS ANTI-SUBMARINE WARFARE (ASW)

In order to help NATO enhance its Anti-Submarine Warfare (ASW) capability in an environment of fiscal austerity, novel ASW solutions based on networks of static and mobile autonomous sensors have been developed in partnership with the Next Generation Autonomous Sensors (NGAS) project.

Dr. Kevin LePage, USA/CMRE

BACKGROUND

Beginning in 2007, CMRE's Cooperative ASW Programme was given the goal to demonstrate a credible networked autonomous ASW capability during dedicated experimentation and NATO ASW exercises.

OBJECTIVE

The objective was to develop embedded signal processing, on-board target classification, tracking, and data fusion, networked underwater communications and, for mobile sensors, autonomy middleware, behaviours and navigation in order to demonstrate networked autonomous ASW.

S&T ACHIEVEMENTS

Results from a total of 13 sea trials have led to the generation of a large number of peer-reviewed articles and NATO publications addressing all major scientific aspects of the autonomous ASW networks. The static and mobile unmanned sensor networks developed are capable of generating real-time detections and tracks, and reporting them back to C2 *via* underwater communications networks.

SYNERGIES AND COMPLEMENTARITIES

The NGAS project run at CMRE 2007-2014 addressed networked autonomous ASW with partner nations: Canada, Germany, Great-Britain, Italy, Norway and the United States of America. Partner nations have provided Sub-Surface Kerosen (SSK) and ship time, scientific manpower and in-kind contributions of sensors, processors and communications networks.

EXPLOITATION AND IMPACT

ASW is a NATO defence planning priority. Autonomous ASW network technology will allow nations to meet their ASW requirements with greater effectiveness and operational flexibility at reduced cost. Autonomous assets for ASW may be operated in forward areas without air superiority or sea dominance. They may be deployed as organic capability and they may be deployed to provide standoff capability. In addition, they offer tactical advantage given the difficulty to counter-detect them. Lastly, they have a high capability to cost ratio, making it more affordable to meet requirements through low acquisition costs.

This work was funded by Allied Command Transformation.

Figure 52: Dr. Kevin LePage receiving his Scientific Achievement Award from the Chief Scientist.

Annexes

ANNEX A – STO PoW ACTIVITIES/DISTRIBUTION

Provided below are graphs and charts detailing the STO's PoW activities/distribution for both the CSO and CMRE.

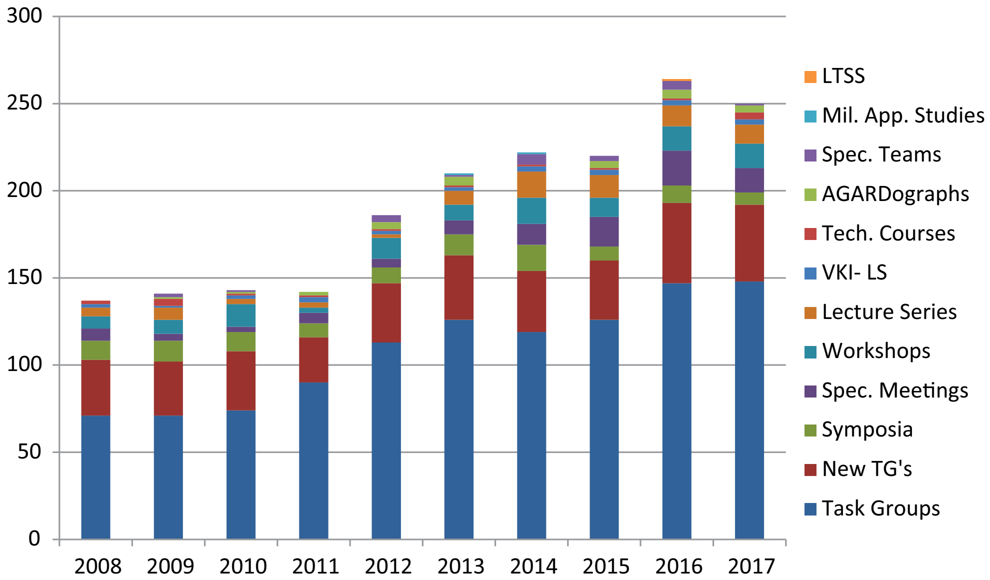

Figure 53: 2017 Trends in STO CPoW.

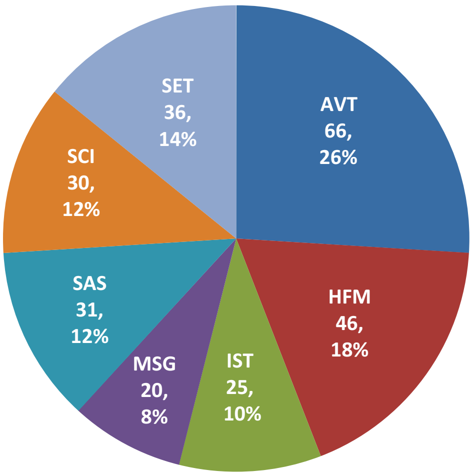

Figure 54: Distribution and number of activities for each panel and group, including all types of activities (task groups, workshops, lecture series...).

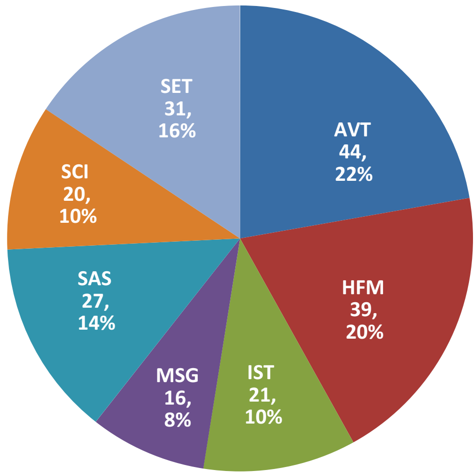

Figure 55: 2017 Number of STO CPoW RTGs per panel and group.

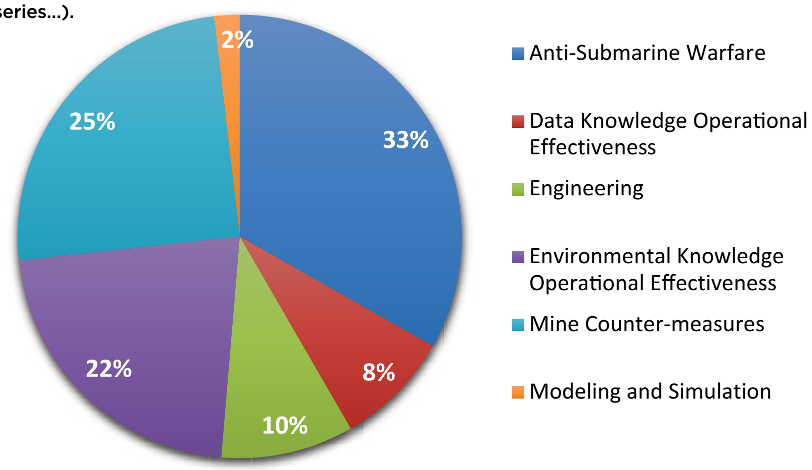

Figure 56: 2017 distribution of activities over the STO CMRE PoW.

ANNEX B – LIST OF ACRONYMS

24/7	24 hours a day / 7 days a week
2D	Two-Dimensional
3D	Three-Dimensional
A2/AD	Anti-Access and Area Denial
ACT	Allied Command Transformation
AF	Air Force
AFB	Air Force Base
AFSC	Alliance Future Surveillance and Control
AIS	Automatic Identification System
AmphibOps	Amphibious Operations
AMSP	Allied Modelling and Simulation Publication
ANMCM	Autonomous Naval Mine Counter-Measures
ASW	Anti-Submarine Warfare
ATR	Automatic Target Recognition
AUS	Australia
AutoLARS	Autonomous Launch And Recovery System
AUV	Autonomous Underwater Vehicle
AVT	Applied Vehicle Technology
AWACS	Airborne Warning And Control System
AWWCG	Above Water Warfare Capability Group
BBC	British Broadcasting Corporation
BEL	Belgium (or Belgian)
BioMedAC	Biological Medical Panel (COMEDS)
BSL	Brillouin Scattering Lidar
C2	Command and Control
C2-DS	Command and Control – Decision Systems
C3	Command, Control, Communications
C4	Command, Control, Communications, and Computers
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CAD	Computer-Aided Design
CAN	Canada
CaT	Architecture Capability Team (NC3B)
CAX	Computer-Assisted eXercise
CBRN	Chemical, Biological, Radiological, and Nuclear
CD&E	Concept Development and Experimentation
Cdr	Commander
CDT	Co-operative Demonstration of Technology
C-IED	Counter Improvised Explosive Device
CMRE	Centre for Maritime Research and Experimentation
CNAD	Conference of National Armaments Directors
CO	Commanding Officer
CoE	Centre of Excellence
CoI	Community of Interest
COL	Colonel
COMEDS	Committee of the Chiefs of Military Medical Services
COP	Common Operational Picture
CPoW	Collaborative Programme of Work
CRV	Coastal Research Vessel
CSO	Collaboration Support Office
CWIX	Coalition Warrior Interoperability exploration, experimentation and examination eXercise
D-CAF	Decoupled Collaborative Autonomy Framework
DDS	Data Distribution Service
DEAR	Directed Energy At Radio (frequencies)
DETOUR	DMPAR Evaluation Trials for Operationally Upgraded Radar
DEU	Germany
DEW	Directed-Energy Weapon
DMPAR	Deployable Multi-band Passive/Active Radar
DMS	Discovery Metadata Specification
DND	Department of National Defence (CAN)
DNK	Denmark
DoD	Department of Defense (USA)

DOTMLPFI	Doctrine, Organization, Training, Material, Leadership, Personnel, Facilities, and Interoperability
DPCS	Defence Planning Capability Survey
DRDC	Defence Research and Development Canada
DRG	Defence Research Group
DSM	Dynamic Spectrum Management
Dstl	Defence Science and Technology Laboratory
EC	European Commission
EDA	European Defence Agency
EO	Electro-Optical
EOP	Enhanced Opportunities Partner
ESA	European Space Agency
ESC	Emerging Security Challenges
ET	Exploratory Team
EU	European Union
EW	Electronic Warfare
FFAO	Framework for Future Allied Operations
FL	Florida (USA)
FOM	Federation Object Model
FRA	France
GBR	Great Britain
GDP	Gross Domestic Product
GE/NL	Germany/Netherlands
Gen	General
GEOMETOC	Geographic, Meteorological, and Oceanographic
GHz	Gigahertz
GNC	German/Dutch Corps
HFM	Human Factors and Medicine
HLA	High-Level Architecture
HPM	High-Power Microwave
HQ	Headquarters
HW	Hybrid Warfare
I&W	Indication and Warning
I/ITSEC	Interservice/Industry Training, Simulation, and Education Conference
IH2	Integrated Health and Healing
IMHM	Integrated Munitions Health Management
In-ISAR	Interferometric Inverse Synthetic Aperture Radar
IPOE	Initial Preparation of Operating Environments
IR	Infra-Red
ISAF	International Security Assistance Force
ISAR	Inverse Synthetic Aperture Radar
IS-DI	International Staff – Defence Investment
ISEG	Independent Scientific Evaluation Group (SPS)
ISR	Intelligence, Surveillance, and Reconnaissance
IST	Information Systems Technology
ITA	Italy
ITU	International Telecommunication Union
JFTC	Joint Force Training Centre
JIP LAURA	Joint Industry Project on Launch and Recovery of Autonomous (systems)
km	kilometre
LIME	Local Inventory Metadata Engine
LOGMEC	Long-Term Glider Missions for Environmental Characterisation
LRTC	Least Restrictive Technical Condition
LS	Lecture Series
LTCR	Long-Term Capability Requirement
M&S	Modelling and Simulation
MAF	Maritime Autonomy Framework
MANEX	Multi-national Autonomous Experiment
MARCOM	Maritime Command
MC	Military Committee
MCCIS	Maritime Command and Control Information System
MCM	Mine CounterMeasures
MCMV	Mine CounterMeasures Vessel
MCR	Minimum Capability Requirement
MD	Medical Doctor
MD	Mediterranean Dialogue
MDCS	Multi-Domain Control Station
MESAS	Modelling and Simulation of Autonomous Systems

METOC	Meteorological and Oceanographic
MGen	Major General
MIMO	Multiple Input, Multiple Output
MoU	Memorandum of Understanding
MS3	M&S Standards Sub-Group
MSA	Maritime Situational Awareness
MUSCLE	Mine-hunting UUV for Shallow-water Covert Littoral Expeditions
NAAG	NATO Army Armaments Group
NAC	North Atlantic Council
NAFAG	NATO Air Force Armaments Group
NATO	North Atlantic Treaty Organization
NC3B	NATO Consultation, Command and Control Board
NCIA	NATO Communications and Information Agency
NCTI	Non-Co-operative Target Identification
NCTR	Non-Co-operative Target Recognition
NDPP	NATO Defence Planning Process
NEMO	Naval Electro Magnetic Operation
NETN	NATO Education and Training Network
NIAG	NATO Industrial Advisory Group
NLD	Netherlands
NLW	Non-Lethal Weapon
NMSG	NATO Modelling and Simulation Group
NMSMP	NATO M&S Master Plan
NNAG	NATO Naval Armaments Group
NOAA	National Oceanographic and Atmospheric Administration
NRV	NATO Research Vessel
NS	NATO SECRET
NSC	NATO Shipping Centre
NSO	NATO Standardisation Office
NSRL	NATO Simulation Resource Library
NTP	NATO Terminology Programme
OCS	Office of the Chief Scientist
OGC	Open Geospatial Consortium
OODA	Observe, Orient, Decide, and Act
Ops	Operations
OR&A	Operational Research and Analysis
PA	Parliamentary Assembly
PARC	Persistent Autonomous Reconfigurable Capability
PCL	Passive Coherent Location
PfP	Partnership for Peace
PoL	Pattern of Life
PoW	Programme of Work
QIA	Quality of Interaction Assessment
R&D	Research and Development
RAdm	Rear Admiral
RDT&E	Research Development Test and Evaluation
REM	Radio Environment Map
ret	Retired
RF	Radio Frequency
RFDEW	Radio Frequency Directed-Energy Weapon
RFW	Radio Frequency Weapon
ROS	Robotic Operating System
RTG	Research Task Group
S&T	Science and Technology
S4	SG/2 Shareable Software Suite
SAA	Scientific Achievement Award
SACT	Supreme Allied Commander Transformation
SAR	Synthetic Aperture Radar
SAS	Systems Analysis and Studies
SCI	Systems Concepts and Integration
SET	Sensors and Electronics Technology
SFA	Strategic Foresight Analysis
SG/2	Sub-Group 2
Smallsat	Small satellite
SME	Subject-Matter Expert
SOA	Service-Oriented Architecture
SPS	Science for Peace and Security
STANAG	NATO Standardisation Agreement
STB	Science and Technology Board
STC	Science and Technology Committee
STO	Science and Technology Organization
SubOps	Submarine Operations

SWE	Sweden
TL	Transmission Loss
TRL	Technology Readiness Level
TTCP	The Technical Collaboration Programme
TTX	Table-Top eXercise
TUR	Turkey
TV	Television
UAS	Unmanned Aerial System
UIMA	Unstructured Information Management Architecture
UK	United Kingdom
UMS	Unmanned Maritime System
US/USA	United States of America
USD	American dollars
UUV	Unmanned Underwater Vehicle
vKHS	von Kármán Horizon Scanning
WPT	Wireless Power Transfer

www.sto.nato.int

organization
CMRE

organization
CSO

organization
OCS

Published March 2018